AFCRL-67-0679

FLIGHT CONTROL SYSTEMS AND LAUNCHING TECHNIQUES FOR AIR BALLAST SYSTEMS

AD 666446

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TECHNICAL NOTE 02057.02-2

Contract F19628-67-C-0192
Project No. 6665
Task No. 666501
Work Unit No. 66650101

Scientific Report No. 2
6 November 1967

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Contract Monitor: James F. Dwyer
Aerospace Instrumentation Laboratory

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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730

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ABSTRACT

This report examines some of the more practical aspects in the application of air ballast systems to the control of free-flight balloons. Each type of air ballast system, as defined in Scientific Report No. 1, is analyzed for the cost, availability of materials, components, and instrumentation required. In addition, for each type of air ballast system deemed feasible, the possible flight system configurations, associated launching problems, and methods to solve the problems are investigated. It is the conclusion of this report that most air ballast systems can be instrumented and flown with conventional or off-the-shelf components and equipment. Systems using very large payloads are more difficult to handle and launch than smaller payload systems and probably will require some development in new launching techniques and associated equipment.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

Section I

INTRODUCTION

This report is a result of a study of various flight control systems and associated instrumentation and launching techniques for air ballast systems. This is the second report relating to air ballast systems. In Scientific Report No. 1[†], air ballast systems are classified into three groups. Within each group are a variety of system configurations. Each configuration, however, works on the same principle; that is changing the displacement weight of the ballast system to compensate for sunset and sunrise effects on a zero-pressure balloon. The first two groups require little or no external power to operate except for that necessary to operate monitoring instrumentation and the ballast valve. The three groups are:

1. Mass expulsion ballast systems.

2. Sealed cell ballast systems.

3. Powered air ballast systems.

A. MASS EXPULSION BALLAST SYSTEM

The mass expulsion ballast system operates like the conventional pourable solid ballast systems. This system carries a mass of air or suitable gas within a superpressure balloon, or ballast bag, to a predetermined daytime operating altitude, at which the gas is under pressure and has a higher density than the outside atmosphere. When sunset occurs, the balloon begins to lose lift due to "sunset effect". At this time, a ballast gas valve is opened and the air or gas within the bag is allowed to escape. The density of the air or gas within the bag decreases, thus decreasing its displacement weight. If the bag is properly designed and the proper mass of gas is inside the bag during the day, then when the air or gas escapes, the displacement weight of the bag will decrease by the same amount as the lift that was lost due to sunset effect. Once the gas is expelled from the ballast bag, the mass expulsion system can no longer operate as a ballast system unless the bag can be refilled again the next day.

[†]Scientific Report No. 1, A Survey of Methods for Controlling the Altitude of Free Balloons with Air Ballast Systems, Air Force Cambridge Research Laboratories, Office of Aerospace Research, USAF, Bedford, Massachusetts, September 29, 1967.

B. SEALED CELL BALLAST SYSTEM

The sealed cell ballast system, like the mass expulsion system, consists of a bag of pressurized air or gas carried aloft with the main balloon to operational altitude during the day. When sunset effect occurs on the main balloon, rather than let the gas escape from the bag, the whole balloon system descends as lift loss is experienced on the main balloon. While the system is descending, the density of the outside atmosphere increases, thus decreasing the differential pressure on the ballast bag. If the gas inside the bag is air, the displacement weight of the ballast system decreases as differential pressure decreases. If the gas is helium, the gross lift of the ballast bag will increase as the differential pressure decreases. With a properly designed ballast system, the balloon system will level out at an altitude where the differential pressure on the ballast bag drops to zero. At this point, the decrease in displacement weight (air-filled bags) or increases in gross lift (helium-filled bags) of the ballast system will compensate the total lift loss due to sunset effect. Unlike the mass expulsion system, the sealed cell ballast system can theoretically operate indefinitely provided the main balloon does not leak helium and the ballast bag does not lose ballasting capability due to gas leakage.

Though the sealed cell air ballast system can allow a balloon system to stay up indefinitely, if the range over which the system travels from day to night is outside the mission objective of the instrument payload, it is necessary to consider the use of the third group of ballast systems.

C. POWERED AIR BALLAST SYSTEM

The function of a powered air ballast system is to accumulate power during the day (usually from the sun), compensate for sunset effect, and utilize stored power during the next morning to re-ballast the balloon system during the sunrise effect.

Within the powered air ballast system group are two basic configurations. The first uses an air compressor on a mass expulsion ballast system to compress outside air into the ballast bag during the morning while solar radiation from the sun superheats the lifting gas in the main balloon. As the lifting gas is superheated, and the lift of the main balloon increases, the outside air is compressed into the ballast bag, thereby increasing the displacement weight of the air ballast system. The total increase in lift of the main balloon due to superheat is therefore compensated by the total increase in displacement weight of the ballast bag when fully pressurized by the air compressor. During the day, solar cells convert solar radiation to electrical energy to charge the batteries in the ballast system. The batteries provide power to the air compressor during the eriod of the sunrise effect. This type of powered air ballast system ca maintain the entire balloon system at nearly constant altitude indefinitely. Its flight duration capability is limited only by the permanent loss of lift due to leakage of gas from the main balloon and the cyclic capability of the power system.

The second type of powered air ballast system consists of a sealed cell ballast system on a powered winch. Instead of allowing the entire balloon system to descend at night to compensate for sunset effect, the winch lowers the sealed cell ballast bag while the main balloon with its instrument payload remains at constant altitude. The power cycle for this system is essentially the same as the powered mass expulsion system. Again, the flight duration capability is indefinite, except now it is limited by leakage of gas from the ballast bag as well as from the main balloon. Notice that in the powered mass expulsion system, any leakage from the ballast bag can be compensated by the air compressor on the bag.

D. CAPABILITIES OF AIR BALLAST SYSTEMS

The gross lift and the amount of sunset effect on the zero-pressure main balloon governs the ballasting requirements from the air ballast system. The capacity of the air ballast system, in turn, depends on the volume of the ballast bag and on the characterisitcs of the ballast bag material; that is, superheat effect, weight, strength, and elasticity. As noted in Report No. 1, bag fabric characteristics limit not only the capabilities of a particular size air ballast system but also the size of the system. For each set of bag fabric characteristics, there exists a maximum or optimum size bag for a given set of operating conditions. If the ballast bag is made any larger than this maximum or optimum size, the payload capability of the whole system is decreased, or else the ballast bag can not structurally withstand the pressures attributed to superheating, much less the pressures required to achieve air ballast. This maximum or optimum size of the ballast bag which limits the payload capability of the balloon system, in turn is dependent not only on the fabric characteristic of the ballast bag but also on the fabric in the main balloon.

The payload capabilities of the air-filled mass expulsion and sealed cell air ballast systems are the same. It was found that, for increasing operational altitudes, the optimum size of the bags increased as well as the payload capabilities of the system. Table 1-1 shows examples where payload capabilities were determined for an air-filled 2-mil Mylar ballast bag carried by a 2-mil Polyethylene zero-pressure main balloon. The sunset effect on main balloon and ballast bag was assumed to be 10 percent.

The payload capabilities of helium-filled sealed cell ballast systems are higher than air-filled systems because of the added lift from the ballast bag. It was noticed, however, that operational altitudes have a smaller effect on the payload capabilities. It was also found that there is no optimum bag size but rather a maximum bag size for which the helium-filled sealed cell system can be made. At this maximum size, the bag can only withstand differential pressures due to its own superheat during the

TABLE 1-1. PAYLOAD CAPABILITIES OF AN AIR-FILLED BALLAST SYSTEM

Daytime operation altitude (ft.)	Optimum bag size radius (ft.)	Volume of main balloon (cu. ft.)	Maximum payload (includes Wt. of instruments & ancillary equipment of ballast system, but not bag Wt.) (pounds)
60K	15	15K	17.4
70K	25	75K	51.2
80K	35	265K	110.0
90K	50	850K	217.0

day; that is the ballast system flies by itself as a superpressure balloon. Table 1-2 lists some payload capabilities of helium-filled systems. These can be compared with the same ballast systems and assumptions made for the air-filled system.

TABLE 1-2. PAYLOAD CAPABILITIES OF A HELIUM-FILLED BALLAST SYSTEM

Daytime operating altitude (ft.)	Bag size radius (ft.)	Payload (less bag weight) (lb.)	Maximum bag size radius (ft.)	Maximum payload (less bag weight) (lb.)
60K	15	80	33	776
70K	25	260	48	1428
80K	35	620	78.5	3852
90K	50	990	125.0	9582

Section II

FLIGHT CONTROL SYSTEMS

A. TEST AND DESIGN EVALUATION INSTRUMENTATION REQUIREMENTS

From Scientific Report No. 1, it was shown that the payload capacity of an air ballast system on a zero-pressure balloon is dependent on bag radius, altitude of operation, superheat temperature both day and night, and the bag fabric stress parameters. For both sealed cell and mass expulsion ballast systems with zero ballast bag superheat at night, it was found that:

$$L' \text{ (payload)} = \left[\frac{32\pi S_1 \; t_b r^2}{Ra \; Ta_1 \; (1+n_1)} - \frac{4\pi \rho_{a_1} \; (1+3S_1/E)n_1 \; r^3}{3(1+n_1)}\right]\left[\frac{1}{N} \; F(\Sigma)^{-1}\right] - 4\pi r^2 \; w_b$$

where

S_1 = Bag stress (psi) during day

t_b = Bag thickness (inches)

r = Bag radius (feet)

R_a = Universal gas content for air

Ta_1 = Ambient day air temperature

n_1 = Ratio of superheat in ballast bag to ambient air temperature

E = Fabric modulus of elasticity (psi)

ρ_{a_1} = Density of air (lb./cu.ft.)

N = Main balloon superheat effect

$F(\Sigma)$ = Ratio of total gross lift to total payload on main balloon

w_b = Ballast bag fabric weight (lb./sq.ft.).

In attempting to determine payload capabilities for specific air ballast systems and main balloons, it was necessary to assume arbitrary values for such parameters as ballast bag superheat, sunset effect in main balloon, and stresses on the ballast bag. Because these parameters greatly effect the payload capacity of an air ballast system, it is necessary to know the value of these parameters accurately, or at least to know the worse case conditions to expect, before designing and flying a balloon system dependent upon an air ballast system. It is envisioned

therefore that early test flights carrying air ballast systems will be flown in a "piggy back" fashion with balloons containing conventional droppable ballast.

The conventional droppable ballast will augment the air ballast so that sunset effect on the main balloon will be compensated completely. This "piggy back" system will allow for heavier payloads, and consequently a more mobile and highly instrumented flight which can be positively controlled and monitored. Therefore, it will be possible to obtain more accurate and realistic values for the design and flight of those balloon systems that depend solely on the ballast available from an air ballast system.

Examination of the payload formula reveals the terms which need to be determined from instrumented flights. Terms such as bag radius, (r), bag material thickness (t), and main balloon payload to gross lift ratio $F(\Sigma)$ are determined by design, and can be ascertained by measurements and quality control in fabrication. Bag fabric modulus of elasticity (E) can be determined fairly accurately under laboratory conditions for the temperatures expected at operating altitudes.

Fabric stress (S_1) determines the amount of pressure the bag contains. Strain gages can measure this stress directly. However, strain gages are difficult to mount on flimsy balloon fabric, and at best, would set up local stresses and constrictions which could produce inaccurate results. It is felt that measurement of differential pressure (ΔP) will produce more accurate data. Fabric stress can be determined mathematically from ΔP by the following formula derived in Report No. 1:

$$\Delta P = \frac{24 S_1 t_t}{r\,(1-3S_1/E)}$$

Since ΔP is uniform throughout the ballast bag, the differential transducer may be mounted wherever convenient, preferably near the instrument package payload. However, the transducer should be located away from the ballast valve, lest local turbulence and partial pressure drops created by the gas escaping through the valve disturb the readings.

Superheat in the main balloon and the ballast bag has a great effect on the ballast system. It is necessary to accurately determine both internal temperatures of the main balloon and ballast bag and the ambient air temperature. Ambient air temperature can be determined fairly easily from a temperature probe, such as a thermistor bead, suspended away from the payload and shielded from radiation from the earth, the sun, and the balloon system itself. A successful method for measuring ambient air temperature is to use small bead[†] thermistor suspended on a line a few hundred feet below the flight train.

[†] Little, A.D. Report No. V, The Measurement of High Altitude Balloon Gas Temperature, R. M. Lucas and G. H. Hall, October 1966.

Temperature measurement of the balloon gas and gas inside the ballast bag can be accomplished by using a small shielded bead thermistor suspended as close as possible to the center of the volume of gas to be measured. The line suspending the thermistor should be attached to the top of the balloon or ballast bag and allowed to hang along the axis of the volume being measured. The use of one temperature probe should be sufficient to measure gas temperature if it is positioned so that it is centrally located and far enough away from the walls of the balloon to prevent its temperature from being coupled to the fabric temperature. As pointed out in A. D. Little Report No. V†,

> "...There is a toroidal mixing of the gas upward along the balloon fabric and downward in the center along the thermistor string so this location for the sensors appears appropriate. The rotational symmetry of the mixing results from the radiative absorption of the fabric on the far as well as near side to the sun and the fact that balloons tend to oscillate in rotation through much of their flight".

Once the ambient air and internal gas temperatures are known, the superheat effect terms for the payload formula can be determined by the following equations:

$$n_1 = \frac{T_{b_1} - T_{a_1}}{T_{a_1}} = \frac{\theta_{b_1}}{T_{a_1}};$$

$$n_2 = \frac{T_{b_2} - T_{a_2}}{T_{a_2}} = \frac{\theta_{b_2}}{T_{a_2}}$$

$$N = N_1 - N_2 = \frac{T_{mb_1} - T_{a_1}}{T_{a_1}} - \frac{T_{mb_2} - T_{a_2}}{T_{a_2}} = \frac{\theta_{mb_1}}{T_{a_1}} - \frac{\theta_{mb_2}}{T_{a_2}}.$$

where,

$T_{b_{1,2}}$ = Ballast bag gas temperature (day, night)

$T_{mb_{1,2}}$ = Main balloon gas temperature (day, night)

$T_{a_{1,2}}$ = Ambient air temperature (day, night).

The superheat effect on the main balloon is determined by the difference between the two ratios for day and night superheat temperature over ambient air temperatures. If ambient air temperature stays nearly the same both day

† Little, A.D. Report No. V, The Measurement of High Altitude Balloon Gas Temperature, R. M. Lucas and G. H. Hall, October 1966.

and night, then

$$N = \frac{\theta_{mb_1} - \theta_{mb_2}}{T_{a_1}} .$$

The last term to be measured for the payload formula is air density (ρ_a), which can be determined from the perfect gas law once ambient air pressure and temperature are found. Therefore, a pressure transducer must be carried that not only provides altitude information, but also the differential air pressure experienced on the ballast bag. Accordingly, the pressure transducer should be located as near to the ballast bag as possible in order to obtain local air conditions around the ballast system.

As a general check on the payload formula and the values of the data taken from the measurements, it is necessary to determine the weight of air ballast taken on or released by the ballast system. For air filled systems this can best be accomplished by use of a strain gage or load cell which continuously monitors the displacement weight of the ballast bag. The difference between the measured displacement weight and the uninflated weight of the ballast bag provides the weight (A) of the air ballast in the bag. This value for A can then be compared with the other measured values through the following formula derived for air ballast weight in Scientific Report No. 1:

$$A_1 = \frac{4}{3}\pi r^3 \,(1+3S_1/E)\left[\frac{P_{a_1} + \Delta P_1}{R_A \, T_{a_1} \,(1+n_1)} - \rho_{a_1}\right]$$

where

A = Air ballast weight (lb.)

P_{a_1} = Ambient air pressure

ΔP_1 = Differential pressure in ballast bag

For helium-filled sealed cell systems, the effective air ballast weight (A_{eff}) can be measured by determining the difference between the day and night lifts of the ballast bag. In this case, the load cell or strain gage measures the lift exerted by the ballast bag. The difference between the day and night lift is related to the other measured values by the following formula, also derived in Scientific Report No. 1:

$$A_{eff} = -\Delta G_b = \frac{32\,\pi r^2\,(1+n_2)S_1 t_b}{R_A\, T_{a_1}\,(1+n_1)} - \frac{4\,\pi r^3\,\rho_{a_1}\,(n_1 - n_2)(1+3S_1/E)}{3\,(1+n_1)} .$$

The gross lift of the ballast bag can be determined by adding the net lift exerted on the load cell to the weight of the ballast bag. The gross lift is determined by the following formula:

$$G_{o_1} = \frac{4\pi r^3 \,(1+3S_1/E)}{3} \left[\rho_{a_1} - \frac{P_{a_1} \quad + \Delta P_1}{R_{He}\, T_{a_1}\, (1+n_1)} \right]$$

where

R_{He} = Universal gas content for helium.

In this manner, it is possible to determine which measurements are absolutely necessary for future flights in monitoring and controlling the balloon systems dependent solely on the air ballast system. Since it has been established from Report No. 1 that air ballast flight systems have limited payload capabilities, it is imperative that the ballast system use the lightest weight instrumentation possible for monitoring and controlling the flight. As a result of early flights, it appears that it will be possible to properly design an air ballast system which can completely compensate the sunset effect on the main vehicle balloon with enough reserve air ballast to cover the entire range of possible ballasting requirements encountered.

B. MONITORING AND CONTROL INSTRUMENTATION REQUIREMENTS

Each of the three air ballast systems requires its own control and monitoring instrumentation. A common requirement for all three systems is the monitoring of altitude through the use of an ambient air pressure transducer in order to ensure the ballast systems are working properly and holding the flight system within the design range of the system. Additionally, differential pressure on the ballast bag should also be monitored to ensure the burst limits of the bag are not reached and that the proper amount of air pressure is present at all times for the ballasting requirements. Finally, determining the displacement weight or lift of the ballast bag will properly monitor the behavior of the ballast system and will alleviate the requirement to measure internal gas temperatures and ambient air temperatures once it is found that the air ballast system is properly designed for all expected conditions.

During the test and evaluation flights on any ballast system, it is necessary to provide a command function to turn on and off magnetic valves for controlling the drop of conventional ballast. It is necessary to determine from the instrumentation what amount of ballast is required for compensating sunset effect and what amount of air ballast is obtainable from the system.

The mass expulsion air ballast system requires a valve to allow the pressurized air in the ballast bag to escape in order to compensate the sunset effect on the main balloon. Therefore, a control function will be required in the instrument package to command the valve to open and close to allow proper discrete amounts of air to be released from the ballast bag. Since large quantities of air need to be released, and in the interest of keeping the ballast valve as light as possible, it may be necessary to have a time lag between the time of the command to open or close the valve and the time when the valve responds. Therefore, in the test and evaluation flights, it may be necessary to monitor the position of the air valve so that the time lag for various altitudes and pressures are known in advance. In this manner it is possible to eliminate instrumentation and associated hardware for monitoring the position of the valve during solo flights. "Solo" flights are defined as flights that depend solely on the ballast available from the air ballast system.

The sealed cell ballast system ideally needs no control instrumentation since the ballasting obtained from the system is determined by design and flight conditions. However, since it is difficult to insert the exact amount of air or helium into the ballast bag while on the ground, it is expected that normal operational procedures will require that an excess amount of air or helium be inserted into the ballast bag at launch and then be released by a relief valve while the flight system ascends to design altitude. This relief valve may be either electrical or mechanical, but must be able to keep the pressure in the ballast bag within a fairly close tolerance. For the test and evaluation flights, it may be desirable to have a combination of a relief valve and a ballast valve, such as one which might be used for the mass expulsion system. The relief valve can then be evaluated for accuracy control, and at the same time allow for positive control of the pressure in the ballast bag in the event the relief valve malfunctions.

The powered air ballast systems require the same instrumentation as the sealed cell and mass expulsion systems and additionally require control instrumentation for the power units themselves. A means for orientating the solar cells to the sun during the day and regulating the charging voltage to the batteries must be provided to ensure the proper amount of power is available to compress air ballast or haul up the ballast bag during the sunrise effect period. For the 2-cycle mass expulsion system, a command function must be provided to turn on and off the air compressor. Built into the compressor unit should be a back-pressure valve so that pressure built up in the ballast bag is retained when the compressor is shut off. For the winch controlled sealed cell ballast system, we need two command functions, one to turn on the electric motor and the second to engage or disengage the clutch on the winch to allow the ballast bag to be hauled up and lowered.

C. REQUIREMENTS SUMMARY

The specific requirements necessary for each type of ballast system are listed below. The requirements are in two groups: measuring instrumentation requirements that are necessary for all ballast systems, and control function and instrumentation requirements that pertain to specific air ballast systems.

Measuring Instrumentation Requirements - The general requirements for all ballast systems are listed below. Table 2-1 lists specific requirements.

1. Instruments shall exhibit no drift or loss of accuracy after repeated temperature and pressure cycling, and after exposure to solar radiation.

2. Instruments shall be unaffected by solar radiation, and when connected to instrument leads, shall be insensitive to electromagnetic radiation, local turbulences, and other interference factors associated with the balloon system.

3. Instruments shall be small, lightweight, and capable of being physically protected during flight. This is particularly important for temperature measurements with thermistor beads.

TABLE 2-1. MEASURING INSTRUMENTATION REQUIREMENTS

Function	Range	Accuracy	Response Time(sec.)	Resolution
Main balloon gas temperature	370°R to 460°R	±1/2°F	1 to 5	±1/4°F
Ballast bag temperature	370°R to 460°R	±1/2°F	1 to 5	±1/4°F
Ambient air temperature	370°R to 420°R	±1/2°F	10 to 20	±1/4°F
Ambient air pressure	1013 to 10 mb (entire flight) 70 to 10 mb (oper. altitude)	±1 mb	1 to 3	±1/2 mb
Differential pressure on ballast bag (8' radius)	0 to 54 mb	±1 mb	1 to 3	±1/2 mb
Differential pressure on ballast bag (50' radius)	0 to 9 mb	±0.2 mb	15 to 20	±0.1 mb
Ballast bag weight*	(W_b-10% A_{eff}) to (W_b+110% A_{eff}): air filled (G_{b_1}-W_b-10% A_{eff}) to (G_{b_1}-W_b+110% A_{eff}): helium filled	±1% of range	1 to 20 (depends on bag size)	±50% of accuracy rqts.

*Examples of ballast bag weight using the indicated requirements are given on the following page.

Example 1 — 8-foot radius, 2-mil Mylar, air-filled bag at 70,000 feet

A_{eff} = 4.59 lb.

Bag weight (W_b) = 18.0 lb.

Range = 17.5 to 23.5 lb.

Accuracy = ±0.06 lb. (± 1 oz.)

Response time = 1 to 3 sec.

Resolution = ±0.03 lb. (± 1/2 oz.)

Example 2 — 25-foot radius, 2-mil Mylar, air-filled bag at 80,000 feet

A_{eff} = 36.6 lb.

Bag weight = 115 lb.

Range = 111 to 155.5 lb.

Accuracy = ±0.45 lb. (± 7 oz.)

Response time = 10 to 12 sec.

Resolution = ±0.23 lb. (± 3.5 oz.)

All the requirements in Table 2-1 are necessary for "piggy-back" flights. The ambient air pressure and differential pressure on ballast bag are the minimum necessary for solo flights.

Control Function and Instrumentation Requirements - The general requirements for control functions and instruments are:

1. All control and power units must survive 30 days flight operations at operating altitude and within the following ranges:

Temperature - 360°R to 420°R

Pressure - 120 to 10 mb

Relative humidity - 0 to 100%

Solar radiation - Intensity expected at 50,000 to 100,000 feet altitude

2. Instruments shall be small, lightweight, and capable of surviving shocks associated with launching and ascent.

3. Instruments shall be properly shielded from flight-train instrumentation to prevent interference to monitoring equipment.

4. Instruments shall require minimum power to operate and still meet specifications in order to reduce weight of batteries and associated power systems.

During test and evaluation "piggy-back" flights, it is necessary to have a control function to operate magnetic ballast valves to discharge conventional ballast. Ideally, a properly designed air ballast system requires no conventional solid ballast. However for purposes of ascent and descent control, as well as compensation for gas leaks, it probably will be necessary to carry some conventional solid ballast during dummy solo flights.

Below are listed the control and instrumentation requirements necessary for a particular type air ballast system.

1. <u>Mass expulsion ballast system</u>

   (a) Air ballast valve (varies with bag size)

   Orifice size - must allow bag to go from full superpressure to zero pressure in 30 minutes.

   Maximum pressure - 9 to 60 mb

   Leakage - 0.1 cu.ft./hr. at 30 mb

   Operation - electrical command, full open to full close in 10 seconds, full close to full open less than 7 seconds.

   Power - DC, 36 watts starting, 12 watts running.

2. <u>Sealed cell system</u>

   (a) Relief valve (varies with bag size)

   Orifice size - must allow air to escape to maintain constant pressure on ballast bag while ascending 1,000 ft./min. between 20,000 and 90,000 feet.

   Maximum pressure - 9 to 60 mb

   Leakage - 0.1 cu.ft./hr. at 30 mb

   Operation - electrical command, remote (optional), self regulating (mechanical desirable), full open to close less than 2 seconds, full close to open less than 1 second.

   Regulation - setting range - 6 to 60 mb

   opening tolerance - $\pm\,{}^{2}_{1}$ mb from setting

   closing tolerance - $\pm\,{}^{1}_{0}$ mb from setting

   response time - 2 sec. open to close
   3 sec. close to open

repeatability - ±0.5 mb

power requirements - DC, 36 watts for electrical control valves; spring, hydraulic for mechanical.

3. Powered 2-cycle mass expulsion system (compressor)

(a) Air ballast valve - same as 1(a.)

(b) Power system

Solar cell orientation - cells should receive 90 percent of sunlight energy for 10 hr./day.

Power regulation - ±2 volts of battery charging voltage. Must detect and stop charging when batteries are fully charged.

Power output - operate all instruments continuously. Must be able to compress ballast bag at least once every 24 hours.

Duration of operation - 30 days.

(c) Compressor

Control - turn compressors on and off by remote command at least five times during compression cycle of 1 hour.

Operation - must be able to fill bag within 1 hour at operational altitude, and start and stop at least five times during 1 hour compression cycle.

Back pressure - range: 9 to 60 mb, leakage less than 0.1 cu.ft./hr. at 30 mb.

Efficiency (motor and compressor) - at least 40% total efficiency; electrical efficiency 50%, adiabatic compressor efficiency 80%.

Volumetric compression - capacity-to-weight ratio - 20 cu.ft./min./lb. (compressor and motor total weight) at operational altitude.

4. Powered sealed cell system (winch).

(a) Relief valve - same as 2(a).

(b) Power system - same as 3(b), except main power switch is to winch controls.

(c) Winch -

Control functions - turn winch on and off remotely at least five times while ballast bag is rising during sunrise effect (1 hour). Engage and disengage clutch to winch at least 20 times while ballast bag is raised or lowered.

Monitoring - measure paid out cable from 0 to 10,000 feet ± 10 feet.

Operation - haul bag from lowest level to highest within 1/2 hour at operational altitude. Be able to start and stop at least five times during 1 hour sunrise effect. Be able to haul in or pay out line and not consume appreciable power when paying out cable.

Efficiency (motor and winch) - electrical greater than 50%; mechanical greater than 90%, total greater than 45%.

Haul-in strength - 40 to 300 pounds depending on bag size (the greater the haul-in strength required, the less haul-in speed and distance required).

Drum capacity - depends on bag size (for example, a 25-foot radius, 2-mil Mylar, air ballast bag at 80,000 feet requires 5,000 feet of 1/16" diameter, 1 x 7 steel cable).

Weight - motor and winch 25 to 35 pounds.

D. INSTRUMENTATION

During balloon ascent to operating altitude, the ballast system instrumentation must withstand the environmental extremes of the atmosphere and perform accurately for extended periods at operating altitudes. These extremes range in temperatures of +110°F to -90°F, pressures from 0 to 15 psia, and humidity from 10 to 100 percent RH. Therefore, it is necessary to ensure that the measuring transducers are designed with compensating networks in the instrument package so that they can accurately measure parameters under all expected conditions. For example, resistance strain gage circuits can be designed to measure absolute pressures with extreme accuracies but if the effects of temperature changes are not considered, errors as high as 15 to 20 percent can result. Sensors are often designed to operate with relatively low excitation power and with operational amplifier networks which compensate for the various atmospheric extremes.

The following list is the result of a survey of available transducers which can meet the measurement requirements for most air ballast systems, as outlined in Section IIC. While not practical to recommend specific instrumentation models since selection is dependent on the mission and size of the ballast system, specific transducers and associated operational amplifiers are presented to indicate typical advertised sizes, weights, accuracies, and costs.

1. Temperature (Ambient and Internal). A 5-mil thermistor bead is considered the best means for accurately measuring air temperature. Due to its small size, a temperature response time of less than 0.5 second can be expected. In addition, it can accurately measure air temperature by conduction with little or no effect from heat loss or absorption by radiation. Accuracies to ±0.5°F can be obtained through proper compensated bridge networks and operational amplifiers.

Care should be taken when designing the thermistor bridge circuit to ensure that the heat dissipation constant is not exceeded over the entire temperature range to be measured. Exceeding this limit causes internal heating of the thermistor thereby inducing errors in the output reading.

Since thermistor beads are small and fragile, they must be housed in protective cages that prevent breakage from buffeting against the side of the bag or balloon during inflation, handling, or launching. The protective cage should be designed to allow the maximum exposure of the bead to the free air or gas, but not cause the bead temperature reading to be affected by the radiation or conduction heating from the cage itself. A report by Lucas and Hall † on techniques for measuring balloon gas temperatures with thermistor beads describes in detail design and fabrication techniques for mounting thermistor beads and associated circuitry.

Thermistor beads range in price from $30.00 to $60.00, depending on mounting options, and are negligible in weight. Bridge circuits and associated operational amplifiers for thermistor beads are obtainable from some bead manufacturer or may be designed from off-the-shelf components. Estimated costs for bridge networks and operational amplifiers range between $200.00 to $300.00. Since a thermistor bead is a sensitive element which changes with temperature, continuous resolution is obtainable within the temperature range of interest.

2. Ambient Air Pressure. Ambient air pressure can be measured by several means such as a bellows or a stressed diaphragm coupled to a transducing element. Techniques for this type of sensor include the use of a strain gage, a mechanical linkage to a linear potentiometer, a coil to produce a variable reluctance, a bridge to produce a variable inductance, and detection of capacitance between the diaphragm to an adjacent electrode. Another basic sensor scheme employed in a hypsometer involves the boiling of a liquid and detection of the temperature of the resultant vapor.

Among these transducers available off-the-shelf, the one which seems best suited for meeting the requirements of an air ballast system is a solid state piezoresistive pressure transducer which utilizes the strain gage principle. The model 4715 pressure transducer by Conrac Corporation is able to obtain an accuracy of ±1 mb over a possible range of 10 to 1013 mb.

The unit consists of a silicon pellet which is evacuated in the center to a near vacuum. An array of resistor strain gages are mounted on one of the outside surfaces of the transducer. From the array, four resistors are selected for a bridge circuit. The selected resistors are in a row across the surface, two of which are in tension while the other two are in compression. As the atmospheric pressure changes, a corresponding change in resistance occurs across the bridge circuit. The remaining resistors of the array not used in the bridge circuit are neglected.

† Lucas, R. M. and Hall, G. H., The Measurement of High Altitude Balloon Gas Temperatures, A. D. Little Report No. V, October 1966, pp 5-14

Listed are some of the pertinent characteristics of Model 4715:

Range - 0 to 15 psia

Accuracy - ±0.2% full scale

Resolution - continuous

Temperature range, compensated -65° to +250°F

Size - 1-1/8" diameter; 1" long

Weight - 3 ounces

Cost - $650.00

Available with the pressure transducer is a 4715H High Level Operational Amplifier which is matched to the 4715 pressure transducer. The amplifier costs approximately $500.00 and has an output of 0 to 5 vdc over the full scale of the transducer.

3. Differential Pressure. The selection of the differential pressure transducer depends on the range of differential pressures expected on the ballast bag. One type of differential pressure transducer which appears suitable for most air ballast applications and is available over most ranges of interest is the Model PL283TC by Statham Instruments, Inc. This transducer utilizes a strain gage coupled to a flexible sensing diaphragm which measures the pressure deflecting it.

The following performance data is advertised for this model transducer:

Range - 0 to 1 psid (0 to 69 mb) Model PL283TC-1-350
0 to 0.15 psid (0 to 10 mb) Model PL283TC-0.15-350

Accuracy - ±0.75% of full scale

Size - 1.75" x 1.29" x 1.44"

Resolution - continuous

Response - less than 1 ms

Temperature range - -65° to +250°F

Weight - 7 ounces

Cost - $450.00

A Model SA23-3 amplifier matched to the Model PL283TC transducer with an output range of 0 to 5 vdc is available for $950.00.

4. Load Cell. The selection of load cells to measure weight or lift of the ballast bag depends on the size and mission of the ballast system.

There are many types of load cells, many of which use strain gages or variable inductance circuits for transducing exerted loads on the cells. While load cells can be found which meet the requirements of most ballast systems, of primary interest are those models which are relatively small and lightweight.

For example, West Coast Research Corporation produces strain gage load cells, models 33, 34, 37 and 39, which can cover a number of load ranges with accuracies better than ±0.5% of full scale with continuous resolution. The following general characteristics are advertised for these models:

Weight - 3 to 6 ounces

Size - 1.5" diameter, 2.5 - 3.5" long

Temperature range - -100 to +450°F

Price - $360.00 to $475.00

The vendor also has available Ampleducer models matched to these load cells which can provide a 0 to 5 vdc signal for approximately $200.00

5. Instrument Package. One factor which became apparent during the sensor survey was the generally small outputs from most strain gage transducers. Normally, with an excitation of 10 vdc an output of 20 millivolts over full scale can be expected, or for every volt of allowable excitation on the bridge circuit, an output of 2 millivolts full scale can be expected. Since in some cases resolutions on the order of one part per thousand are required, the circuits external to the sensor must be capable of resolving 20 microvolt steps for transducers with 20 millivolt full scale outputs. Under ideal conditions this is difficult but when the factors of temperature, pressure, and humidity are considered, the resolution problem is compounded. For this reason, it was decided that the output voltage of each sensor should be amplified, and that the simplest approach would be to purchase a corresponding amplifier with each transducer. This would provide a 0 to 5 vdc output compatible with the input requirements for standard telemetry equipment. The amplifier, therefore, should be matched to the transducers. For example, if the transducer output is linear over full scale, so should the amplifier output.

Figure 2-1 shows a proposed block diagram of the data gathering system. Each sensor has its own corresponding amplifier which provides a 0 to 5 vdc output. The output from the amplifier is fed to an accurately calibrated VCO which has a standard IRIG center frequency and deviation. VCO's which can resolve one part per thousand or 5 millivolts in 5 vdc are not uncommon. Selection of a standard IRIG channel permits operations at any of the many government test ranges. These sites normally contain the necessary GST equipment required to extract the data.

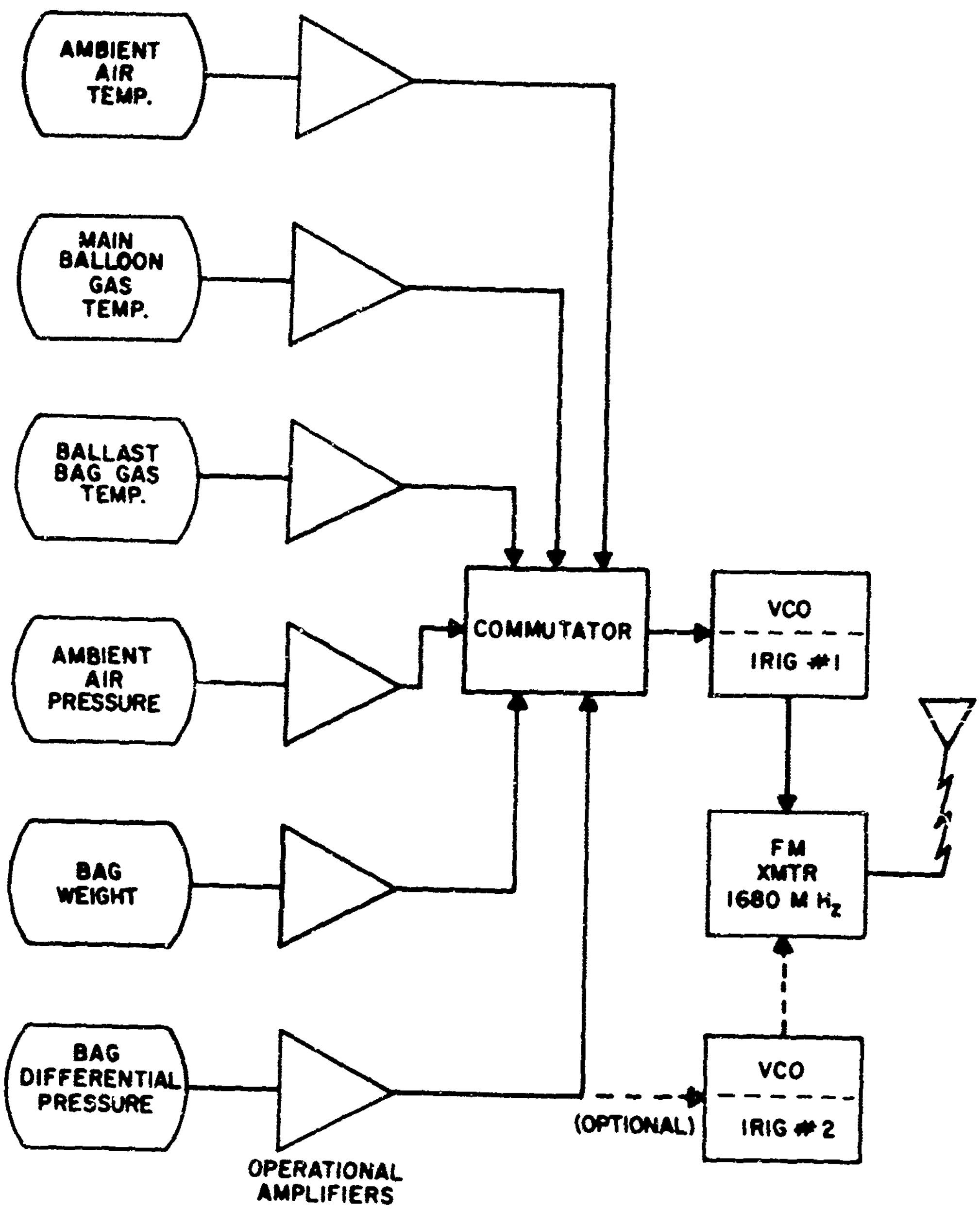


Figure 2-1. Block Diagram of Ballast System Telemetry System

The block diagram shows a system utilizing a single IRIG channel. The commutator switches from one sensor to another thus allowing sequential

readings in the order programmed by the commutator. The commutator may be a stepping switch or a revolving drum which is divided into the required number of sectors and the signal picked off from a wiper. Since a relatively small amount of data is required, a low data transmission rate on the order of 10 to 20 bits per minute is permissible. It may be desirable to read ballast bag differential pressure on every other reading since this measurement changes rapidly when the ballast system changes altitude or when the ballast valve is opened.

A 1680 megahertz FM transmitter is recommended to be used for this system. If the balloon system can carry a transmitter which can handle more than one IRIG channel for the ballast system data, it may be desirable to use a separate channel for differential pressure, as indicated in Figure 2-1. Other data, such as temperature and ambient air pressure, does not change as rapidly, thus they may be commutated on the other channel.

E. BALLAST BAG VALVES

A ballast bag valve can serve two basic purposes. The first is to exhaust all pressure from the bag, such as for the mass expulsion ballast system. The second is to regulate the pressure within the bag to prevent pressure buildup from exceeding specified limits, such as in an ascending sealed cell ballast system. In either case, it is desirable to design a valve that is lightweight and reasonably uncomplicated for high operational reliability. Therefore, if a ballast system requires both functions, such as a mass expulsion system, a single valve designed to serve both functions is desirable.

The size of a ballast bag valve depends first on the mission and secondly on the size of the ballast bag. The requirements of a ballast bag valve for a mass expulsion system will be examined first. Its prime mission is to valve out air inside the bag so that the differential pressure on the bag is reduced to zero at the time the sunset effect takes place on the main balloon. The secondary mission is to bleed off air while the bag is ascending to operational altitude if the bag becomes overpressured due to being filled with too much air at launch. Assume for now that the excess amount of air inserted into the bag is small and that the flow rate of air required from the bag while ascending is equal or less than the flow rate required for ballasting within the time interval for sunset effect. The flow rates required for ascending ballast bags with excess gas will be discussed later.

From past experience it was noted that sunset effect takes place within 1 hour but that the majority of the lift loss of the balloon takes place within 1/2-hour after the sun sets. Therefore, the valve should be large enough to allow the bag to lose most of its pressure within 1/2-hour. At the same time however, the valve should not be too large as it requires more power to operate a larger valve. Also, a large valve is more difficult to fabricate and seal tightly than a small valve with the same back pressure. It is therefore desirable to determine the minimum orifice diameter that can exhaust the ballast bag to a sufficiently low pressure in less than 30 minutes.

As a conservative approach assume the gas in the bag expands adiabatically, as this type of expansion yields the lowest flow rate. Actually the expansion is polytropic since a continual heat exchange is occuring within the bag from the convective heat transfer with ambient air and radiation heat transfer to and from the earth's surface. Appendix A outlines the theory for exhausting pressure in vessels through circular orifices. Table 2-2 was determined assuming that the bag is sufficiently exhausted if its pressure after 30 minutes is between 0 to 1.0 percent of the pressure before the ballast valve was opened.

TABLE 2-2 BALLAST BAG VALVE ORIFICE SIZES FOR MASS EXPULSION AIR BALLAST SYSTEMS

Ballast Bag Diameter (ft.)	Valve Orifice Diameter (in.)
100	6.5
80	4.6
60	3.0
40	1.6
30	1.0
20	0.6
10	0.2

Using this same technique let us now look at the ballast valve requirements for an ascending system with an excess amount of gas in the bag. For most balloon systems, no matter how much free lift is in the system, the maximum ascent velocity is on the order of 1,000 to 1,200 feet per minute. In addition, as is discussed in Section IIIB concerning the launching and handling of various ballast systems, the smaller the ballast bag the more excess gas in the bag, especially for helium-filled sealed cell systems.

Appendix B discusses briefly a method for determining the required orifice size of a relief valve for an ascending ballast bag. Table 2-3 was formulated to give a general range of valve sizes required for various size bags. Note the wider range of valve size requirements. This range is attributed primarily to the assumption that the percentage of excess gas is the same for all sizes of bags. Actually, for the largest bags, the percentage of excess gas would be much smaller and correspondingly so would the relief valve size.

TABLE 2-3. RELIEF VALVE ORIFICE SIZES FOR ASCENDING BALLAST BAGS

Ballast Bag Diameter (ft.)	Valve Orifice Diameter (in.)
100	13.3
50	3.84
16	.596

Since the pressure inside the bag is nearly the same everywhere on the surface, the valve can be mounted wherever convenient. Since power may be required for the valve, it may be preferable to locate it as near as possible to the power supply in the payload of the balloon system so as to minimize line voltage drop. Depending on the weight penalties and size of the bag, it may be desirable to mount the valve directly on a reinforced patch to the skin of the bag. If the bag has a metal fitting with a removable plate on one end, it would be best to mount the valve to the metal plate.

The valve must have a positive seal to prevent leakage from the superpressured ballast bag and a consequent loss of ballast. A rigid dome pressed against a resilient gasket on a rigid flat ring is a successful sealing technique for balloon valves. This technique is employed in the design of the EV-13 helium valve which is commercially available with a 13 inch diameter orifice. The design can be modified to provide this type valve with the 6-inch, 4-inch and 2-inch diameter orifices.

To date, there are relatively few commercially available balloon valves, and it is felt those that are available require some modification to meet the requirements for a particular air ballast system. For example, Stratotech Company of California produces relief valves for superpressure balloons. These valves range in orifice size from 15/16 inches to 2 inches in diameter and work mechanically with preset springs. They can be set for operating pressures from 10 to 60 mb with accuracies of ±10 percent. For small bags of 25 feet or less in diameter, this type valve is suitable. The valve has a release button allowing the valve to be opened manually. It can be opened electrically if modified by a solenoid plunger or a small motor driven linear actuator. A relief valve of this type weighs a few ounces, including the mounting and hardware. Excluding the cost for modifications, prices of these valves range from $2.00 to $25.00, depending on quality and accuracy.

A mechanically operated relief valve modified to be electrically actuated is suitable for all types of air ballast systems. However, due to the inherent inability to operate accurately at small differential pressures, mechanical valves do not at this time appear to be feasible for use with large

ballast systems which operate at low pressures (10 mb or less). Therefore, it is necessary to design an electrically driven valve which can work in conjunction with a low differential pressure transducer. The pressure transducer can monitor the pressure and with appropriate circuitry automatically command the valve to open when the pressure inside the bag exceeds a specified value. If the dome is mounted toward the interior side of the ballast bag, the pressure in the bag exerts a sealing force on the dome. In this position the valve would be required to open against the ballast bag superpressure to exhaust the air ballast. The maximum force on the dome (the product of the maximum superpressure and the orifice area) is less than 4 pounds. The motor actuator of the EV-13 type valve can drive the dome with up to 25 pounds providing an ample safety factor to guarantee the capability of opening the valve against the ballast bag pressure. The drive motor requires a 12 vdc source providing 3.0 amperes starting current and 1.0 ampere running current. Balloon manufacturing techniques are available for mounting valves of this size and weight in balloons for superpressure use without degradation in the performance of the ballast bag.

A complete 6-inch valve could weigh around 4.0 pounds with the 2-inch valve weighing only slightly less. In units of one or two each, the cost of the valves would be approximately $1,000 due to limited production and precision fabrication. Cost of the controlling circuitry and pressure transducers would be extra.

SECTION III

FLIGHT SYSTEM CONFIGURATIONS

A. GENERAL

Two major problems must be considered in the configuration design of air ballast controlled balloon systems. The first problem is to minimize the load stresses exerted on the ballast bag during launch and flight of the balloon system. A spherical shaped, superpressure balloon does not lend itself to directly supporting loads either due to its own weight or for payloads slung underneath, as does a natural shape or cylindrical balloon. Load stress on a balloon fabric is a function of the balloon cone angle, θ. The smaller the cone angle, the smaller the load stresses on the balloon fabric. Since the bottom cone angle of a spherical balloon is nearly 180°, if a load were suspended there, the load stresses exerted on the fabric near the bottom would become very large or else the bag would be distorted, thus reducing the volume of the bag. It may be desirable to use load tapes attached slightly below the mid point of each gore of the ballast bag as shown in Figure 3-1. In this manner, the cone

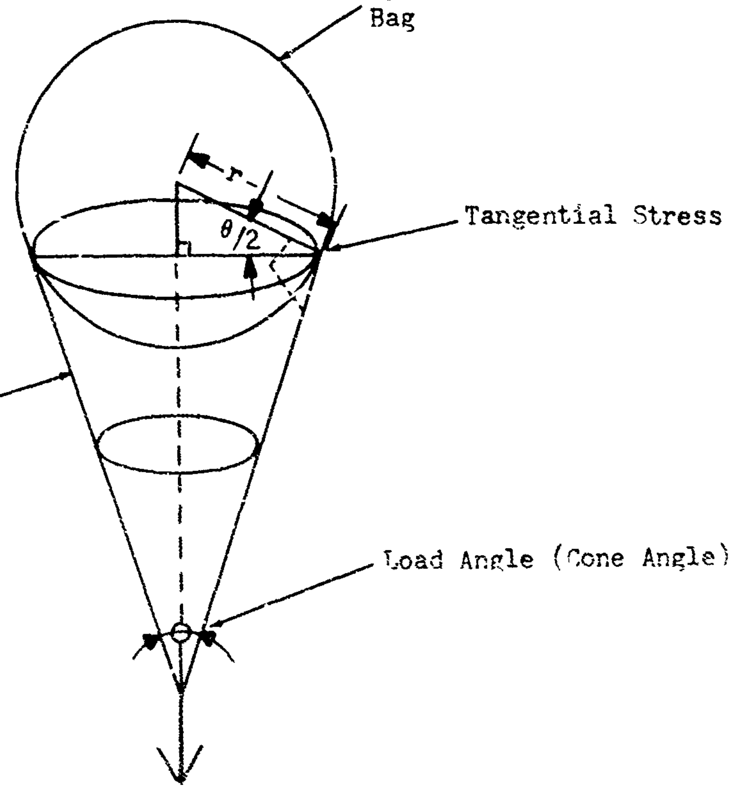


Figure 3-1. Typical Load Configuration on Spherical Superpressure Balloons

angle, or in this case the load angle, θ, can be decreased, thereby allowing the fabric load stress to be decreased. The total linear stress, s_{total}, on the balloon fabric is equal to the sum of the load stress, s_{load}, plus the overall stress on the bag fabric, $s_{\Delta p}$, due to differential pressure, that is, $s_{total} = s_{load} + s_{\Delta p}$. In Report No. 1, it was shown that the payload capability and flight control of a balloon flight train with an air ballast system is greatly affected by the maximum allowable differential pressure in the ballast bag. Therefore, since the maximum allowable differential pressure is proportional to the maximum allowable overall stress, $s_{\Delta p}$, on the balloon due to differentail pressure, s_{load} should be minimized. From Figure 3-1, we see that

$$2 \pi r \cos(\theta/2) s_{load} = F/\cos(\theta/2)$$

or

$$s_{load} = \frac{F}{2 \pi r \cos^2(\theta/2)}$$

where,

s_{load} = linear load stress on bag fabric (lb./ft.)

F = load force

r = bag radius

θ = load or cone angle

By minimizing load force, F, and by decreasing cone angle θ, s_{load} can be minimized. As $\theta \rightarrow 0$, then $s_{load} \rightarrow F/2 \pi r$. But to decrease θ, we need to lengthen the load tapes. There is a point of diminishing return using this approach since the longer the load tapes, the more dead weight we place on the ballast system for suspending the ballast bag. Also, excessively long load tapes greatly increase the length of the flight train and correspondingly the launching and handling problem for the entire balloon system. Therefore, concentration should be placed on decreasing the load force, F, as much as possible, and designing the length of the load tapes for the ballast bag suspension system so that the cone angle is decreased to where the dead weight of the suspension for the ballast bag and the launching and handling problems are not appreciably increased.

The other major problem to be considered is the launching and handling techniques that are required for a particular design of a balloon system flight configuration. For example, the use of long load tapes helps decrease the load stresses on the ballast bag. If the instrument payload were suspended directly beneath the main balloon, and the ballast bag with long load tapes were suspended under the payload, there could be a problem in erecting such a system. In this configuration, the heavy payload would be suspended high off the ground at full system erection. Any appreciable winds or gusts would make it difficult to control the flight train prior to launch.

The following paragraphs discuss possible flight configurations, and possible handling and launching methods for each group of ballast systems. Within each group those flight configurations which lend themselves to conventional handling and launching techniques are discussed first. This includes the use of launch roller arms for inflating single cell poly balloons, payloads suspended on boom cranes, and the conventional launch of single cell balloons. For each flight configuration, inflation, erection, and launch techniques which appear to be the most practical utilizing existing equipment are covered.

For large ballast systems which cannot be handled and launched with regular equipment, possible flight configurations and handling and launching techniques which may be used are discussed briefly. Those areas which require development in fabrication, additional launching equipment, and areas for further study in developing handling and launching techniques for large ballast systems are indicated.

B. AIR-FILLED MASS EXPULSION AND SEALED CELL AIR BALLAST SYSTEMS

Ideal Flight Configuration. The basic difference between the mass expulsion and air-filled sealed cell ballast system is method of operation; however, both systems can be accommodated by the same flight configuration. Since a ballast bag filled with air has a positive displacement weight, it appears logical that the ballast bag be suspended from the bottom of the flight train, as shown in Figure 3-2. The launching and

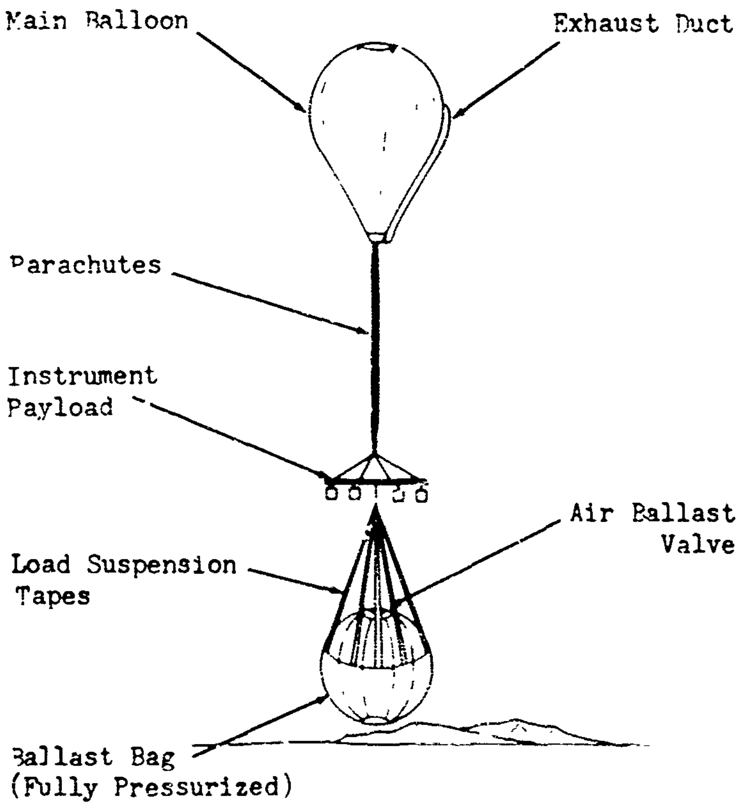


Figure 3-2. Flight Configuration for Air-Filled Ballast Bag Flight System

handling of this type of flight configuration is similar to a regular balloon flight system with the exception of the large volume ballast bag as part of the payload.

The load stress exerted on the ballast bag is attributed only to the displacement weight of the ballast bag (bag weight + air ballast weight). The only other location for the ballast bag on the flight train that could reduce this load stress is on top of the main balloon. However, if the ballast bag (which always has a positive displacement weight) were on top of the main balloon, there would be a handling problem for the top-heavy main balloon during the inflation and erection phases of the launch. Also, there would be a tendency for the ballast bag to roll and shift about unless it were tightly held down to the main balloon by support tapes. In this case, however, the stresses for restraining the balloon would be as high or higher than those experienced by the bag suspended under the payload.

Typical load stresses that might be experienced on the ballast bag for the flight configuration shown in Figure 3-2 will be examined. Assume a 2-mil 25-foot radius, Mylar ballast bag fully pressurized at 80,000 feet. From Report 1, it was found that:

W_b	(bag weight)	= 115 pounds
A_1	(air ballast displacement weight)	= 36.6 pounds
F	(total force)	= 151.6 pounds

Assume that the suspension tapes on the ballast bag are long enough to give a load angle θ equal to 40°. Using Figure 3-1, the length of the load tapes are approximately,

$$\frac{25 \text{ feet}}{\tan (40°/2)} = 69 \text{ feet} .$$

The distance (L) (from the top of the load suspension tape to the bottom end cap) is determined by the following formula:

$$L = r + \frac{r}{\sin \theta/2} = 25 + 73 = 108 \text{ feet}$$

The linear load stress (s_{load}) on the ballast bag fabric is given by:

$$s_{load} = \frac{F}{2 r \cos^2 \theta/2} = \frac{151.6}{2 \cdot 25 \cdot \cos^2 \frac{(40°)}{2}} = 1.09 \text{ lb./ft.}$$

The total allowable linear stress on the ballast bag material has been given as 240 lb./ft. Hence the allowable stress for differential

pressure, $s_{\Delta p}$, is reduced by a factor of less than 0.5 percent. Therefore, for this flight configuration, the ballasting capability of the ballast bag decreases by only a negligible amount.

Inflation Techniques. Now consider some of the launching and handling problems associated with this flight configuration. One of the more popular methods used by the Air Force for launching and handling reasonably small payloads on single cell poly balloons involves the use of an inflation roller arm to establish the bubble during inflation. The payload is often made up of a series of small instrument packages fastened to a load bar, which is held up by a boom crane, 15- to 25-feet high, depending on the payload size. The payload and balloon are tied together through a set of parachutes, which are used for descent. A typical configuration is shown in Figure 3-3.

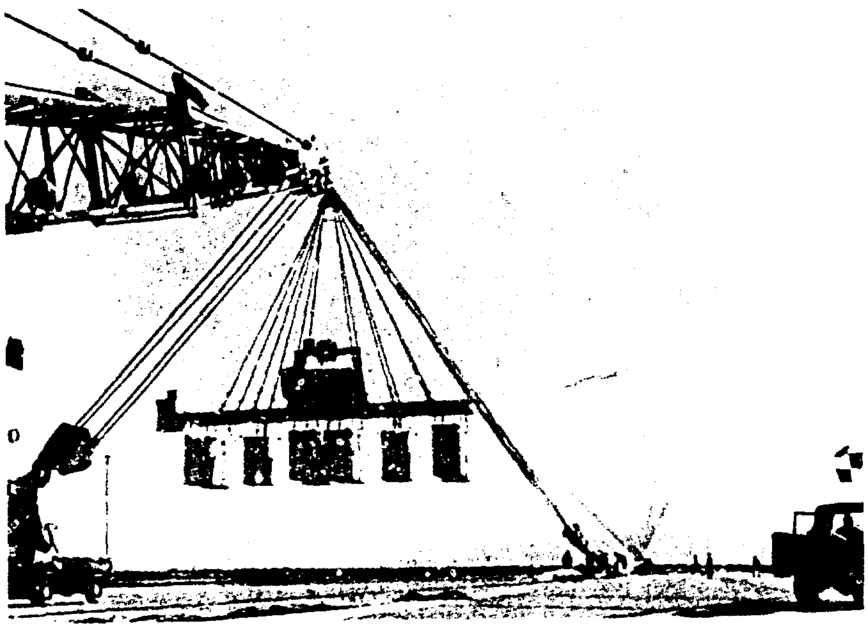


Figure 3-3. Typical Inflation Configuration of Single Cell Poly Balloons

Once the poly balloon is inflated and allowed to fly up out of the roller arm, the flight train is erected and the system is ready to be dynamically launched. While still holding the payload, the crane moves down wind with the entire erected flight train. The payload is released when the main balloon is directly over the payload. At this point the system is launched and begins to ascend. This type of launch is wind limited, primarily, to the top maneuvering speed of the crane holding the payload.

Handling Techniques. Assuming a launch technique just described is used for a payload containing an air-filled ballast bag, several problems such as how the ballast bag can be filled with air, attached to the load bar. and handled by the boom crane until launch must be considered. Consider the previous example using a 25-foot radius ballast bag. The total length (L) of the ballast bag system suspended under the load bar is more than 100 feet long when fully deployed at operating altitude. When the ballast bag is on the ground, the volume of air in the bag is considerably smaller. Hence, the bag should be filled with enough air so that it is full and under proper superpressure at operating altitude. The excess fabric of the ballast bag and its suspension tapes can be folded up for launch. In the example, the bag is to be fully superpressured during the day at the operating altitude of 80,000 feet. From Report No. 1 it was found that a 25-foot radius sealed cell bag will descent from 80,000 feet to about 75,000 feet during the night, at which point the bag will have zero differential pressure. A unit volume of air at sea level expands approximately 22 times at this altitude. Therefore, the radius of a bubble of air increases by a factor of $\sqrt[3]{22} = 2.8$, thus the required diameter of the air bubble in the 25-foot radius ballast bag on the ground is about 18 feet.

It is possible to launch an empty ballast bag and fill it with air while ascending to operating altitude by means of air scoops, pressure tanks, or other similar devices. However, severe weight penalties and control complications would be added to the ballast system. Also, there are additional problems of ensuring that the proper amount of air is inserted into the ballast bag and that the air valve closes at the proper time and does not leak out the superpressured air. It is therefore suggested that a simple and more reliable method for ensuring that the proper amount of air is in the ballast bag is to insert a metered amount of air while the bag is on the ground.

One method for filling the ballast bag while on the ground and attaching it to the load bar is shown in Figure 3-4. A ground cloth is first laid out underneath the load bar that is held up by a boom crane. A lightweight net is placed over the ground cloth. The ballast bag is partially spread out on the net, and its suspension lines are tied together on a ring fastened to the load bar. On each corner of the net are small rings or loops which permit ground crew personnel to lift the net on each corner and tie the corners together with a single loop of nylon cord onto the load bar. In this fashion, the ballast bag is cradled inside the net. The inflation hose is left hanging out the net to permit the ballast bag to be filled. The netting around the ballast bag performs three functions: first, it provides a method for folding up the excess bag fabric and suspension tapes, and restricts the length of the ballast system during launch to about the diameter of the required bubble of air. Second, it keeps the ballast bag bubble in a reasonably firm shape, thereby reducing wind drag force on the payload during launch. Third, it prevents the bag from sailing during inflation and launching.

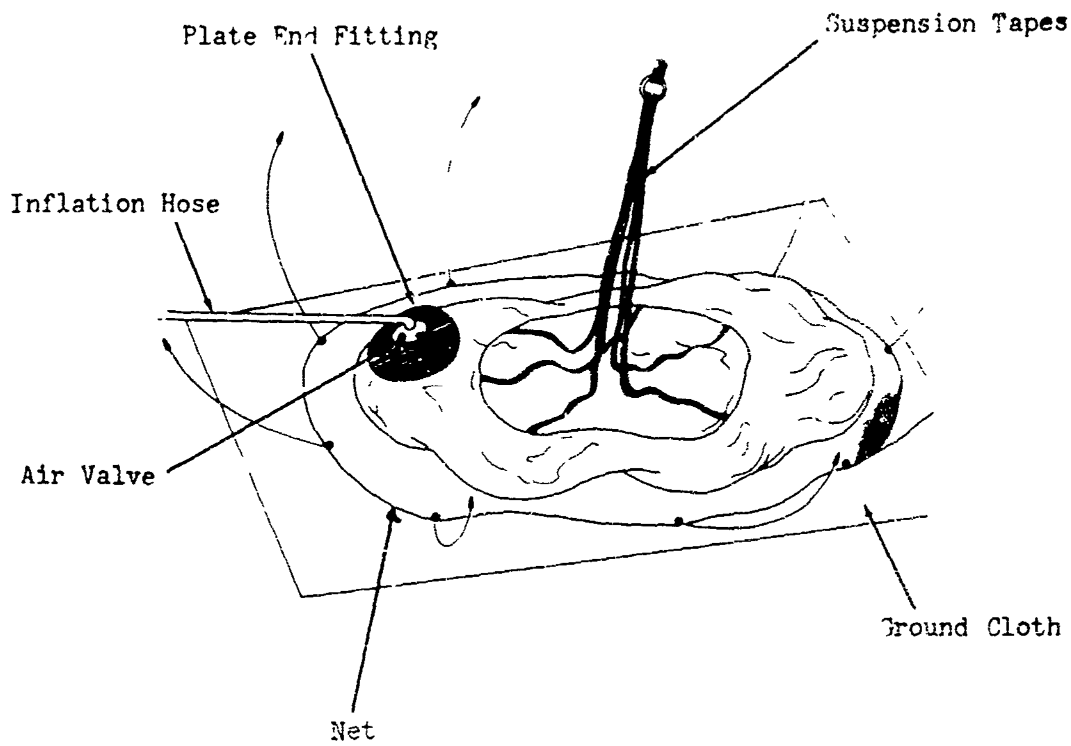


Figure 3-4. Inflation of Ballast Bag with Air

Figure 3-5 shows the configuration of a partially inflated ballast bag bubble suspended on the load bar while the main balloon is being inflated. The nylon cord used to tie the corners of the net onto the load bar can be threaded through an explosive line cutter, which allows the net to be remotely released and the ballast bag to fully deploy after the balloon system is launched. The line cutter squibs can be activated by a transmitted signal to the instrument package. However, for simplicity in launch procedures, the squibs can be automatically fired by the closing of a baroswitch set for a few thousand feet above the ground level. Another method for automatically releasing the net is to have a long line fastened to the ground and connected to a pin puller on the load bar. After launch, when the payload is well above the ground, the line pulls out the pin and releases the net. The net can also be connected to the ground line to assure that the net will pull off the ballast bag and not hang up on the payload.

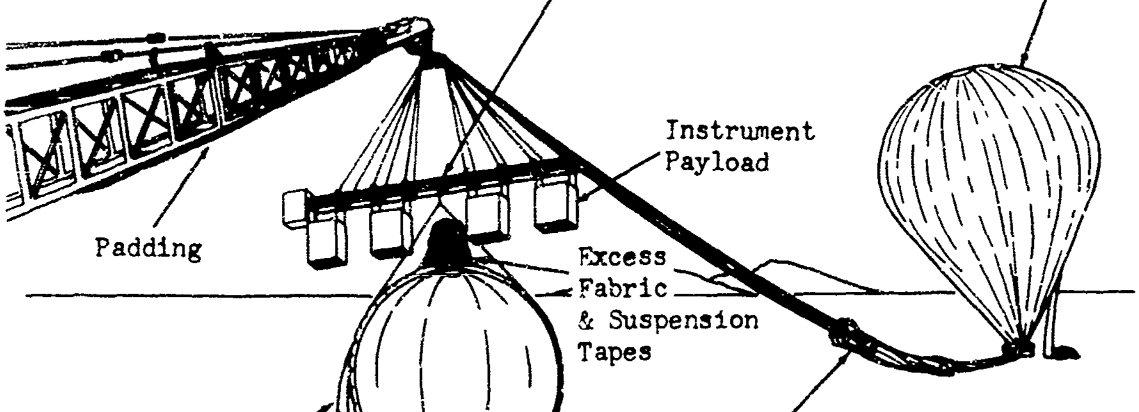


Figure 3-5. Handling of Air-Filled Ballast Bag During Inflation Phase of Main Balloon

Restrictions. The size of the ballast bag bubble depends on both the size of the bag and the operating altitude of the balloon system. As demonstrated in Appendix C, a crane with a 30-foot boom and 10-foot extension can handle bubbles ranging in size up to 20 feet in diameter. However, ballast bags which require a bubble of air greater than this diameter do not lend themselves to the procedures and techniques just described. Table 3-1 lists the size restrictions for this launch technique.

TABLE 3-1. LAUNCH RESTRICTIONS FOR A 40-FOOT BOOM CRANE

Daytime operating altitude (1000 ft.)	Radius of bag with 10' radius bubble on ground (ft.)	Optimum bag size radius (ft.)*
60	21.4	15
**70	24.8	25
80	28.8	35
90	32.8	50

*From Table 1-1
**Note that for operating altitudes up to 70,000 feet there is no restriction on size of the ballast system than can be handled by a crane, since the optimum bag sizes up to 70,000 feet operating altitude require bubbles less than 20 feet diameter on the ground. For operating altitudes higher than 70,000 feet, it is necessary to consider other flight configurations and launch techniques for large ballast systems with bags greater than 50 feet diameter.

Launching Large Ballast Systems. If it were desirable to use the same flight configuration for large ballast systems as for small ballast systems, a static launch might be employed. With this method, the main balloon is allowed to erect the flight train with the payload to a launch configuration as shown in Figure 3-6.

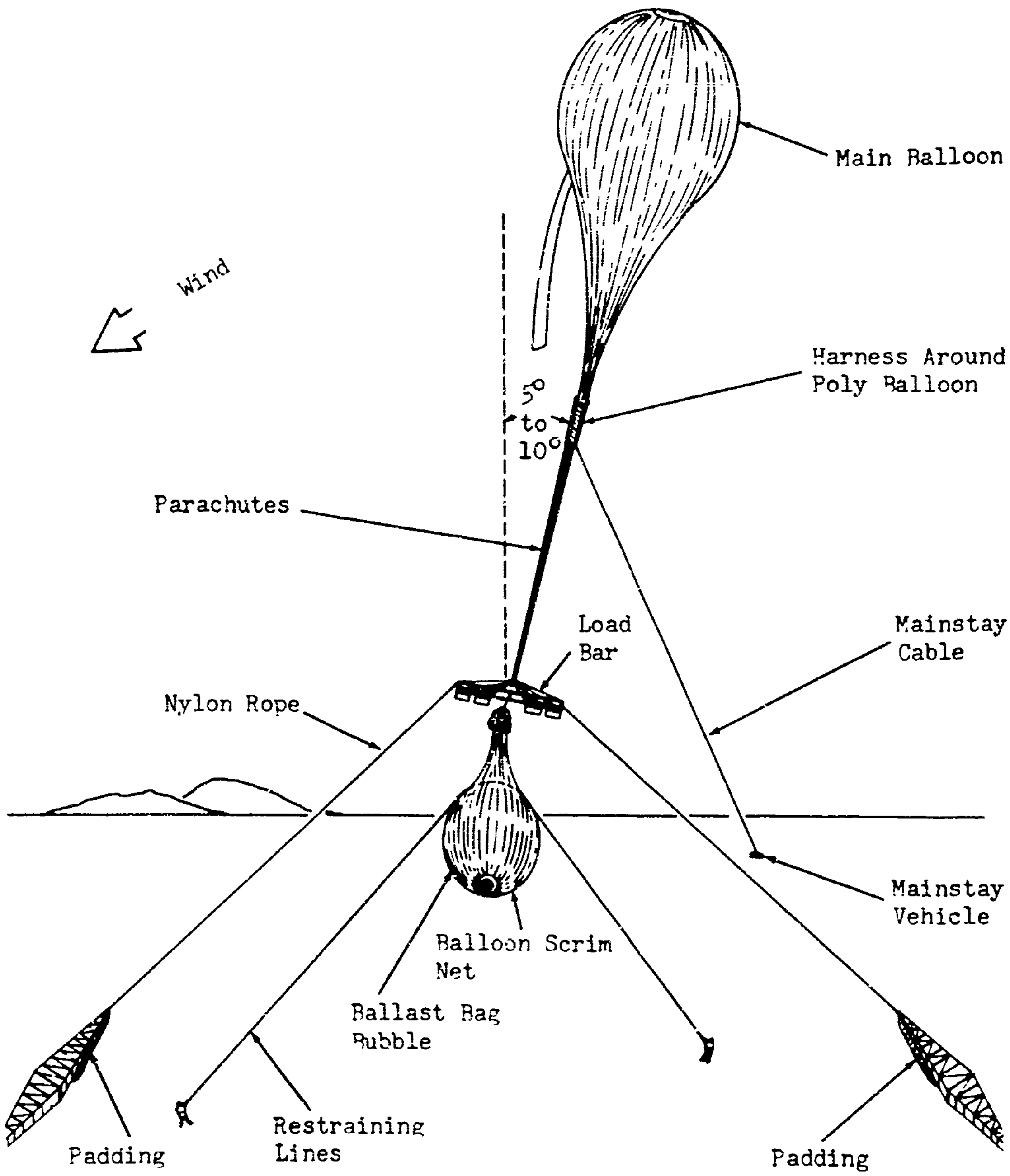


Figure 3-6. Static Launch Configuration for Large Air-Filled Ballast Bags

The harness or girdle around the main balloon holds it in a firm [illegible] and provides a convenient attachment point for the mainstay cable to hold the balloon. When the balloon system is ready to be launched, a set of squibs breaks apart the harness and allows the balloon to be released from the mainstay while the harness falls clear.

The wind restrictions for a static launch are about the same or less than for a dynamic launch, but the handling procedures are more complicated. For example, if the largest available crane can hold the payload only 30 feet above ground and the bubble is 40 feet in diameter, it is necessary to suspend the load bar below the level of the top of the ballast bag bubble while the main balloon is being inflated. In this case two cranes are proposed to restrain the erected payload instead of ground anchors.

Restraining lines fastened to the netting should be used to hold the bubble over the ground cloth. When the main balloon is fully inflated, the launch arm releases the main balloon, which is then held down by the mainstay cable. The mainstay vehicle then pays out mainstay cable, allowing the whole flight train to be erected. When the flight train is erected, the cranes can pay out the cables attached to the load bar, allowing the flight train to hoist the load bar above the ballast bag bubble. When the flight train is raised high enough off the ground to lift the ballast bag bubble, the system can then be launched.

The primary purpose of the two cranes is to provide complete control of the payload on the load bar while the flight train is erected and to suspend the load bar as high and near as possible to the top of the bubble so that the flight train can lift off the ballast bag bubble straight up without a twisting motion. Naturally the crane booms should be well padded for protection of the ballast bag.

The launch configuration of the flight train, as shown in Figure 3-6, has the mainstay vehicle pulling the flight train 5 to 10° from the vertical into the wind. When the system is ready to launch, the mainstay cable and harness are first squibbed off. At this point, the flight train swings up with the wind to a vertical position. When the flight train is fully erected (straight up and down), the two lines from the boom cranes to the load bar are squibbed off, releasing the payload. The restraining lines to the ballast bag net are then released at the ground. As the system rises, a baroswitch closes at a predetermined height and squibs off the net. The net, along with restraining lines, falls from the ballast bag, which then deploys to its full flight configuration length.

Normally, static launches have more or less been restricted to tandem balloon systems such as Stratoscope II, HAPPE, Project Voyager, and other heavy payload balloon systems. The harness around the main balloon would allow a single cell balloon to assume a pseudo-tandem balloon configuration, thus allowing it to be handled like a tandem balloon. The harness concept has been proposed previously, but to date has not been developed sufficiently to provide a workable erection and static launch technique for single cell poly balloons. It therefore will be necessary to conduct a study and development program on methods and launch equipment required for statically launching

single cell poly balloon before large ballast systems in the flight configuration shown in Figure 3-6 can be launched.

The dynamic launch of large air-filled ballast systems however, is not considered practical with existing launch equipment unless a different flight configuration is used. One possible configuration, for example, which might be used with existing launch equipment, is to have a center load cable running through the middle of the bag, suspending the bag between the bottom of the flight train parachutes and the payload. The ballast bag could be constrained in a sausage-like fashion by a sheath or netting while partially inflated on the ground, as shown in Figure 3-7. In this manner, the ballast bag becomes an integral part of the entire length of the flight train which can be erected and launched in the usual manner for a dynamic launch.

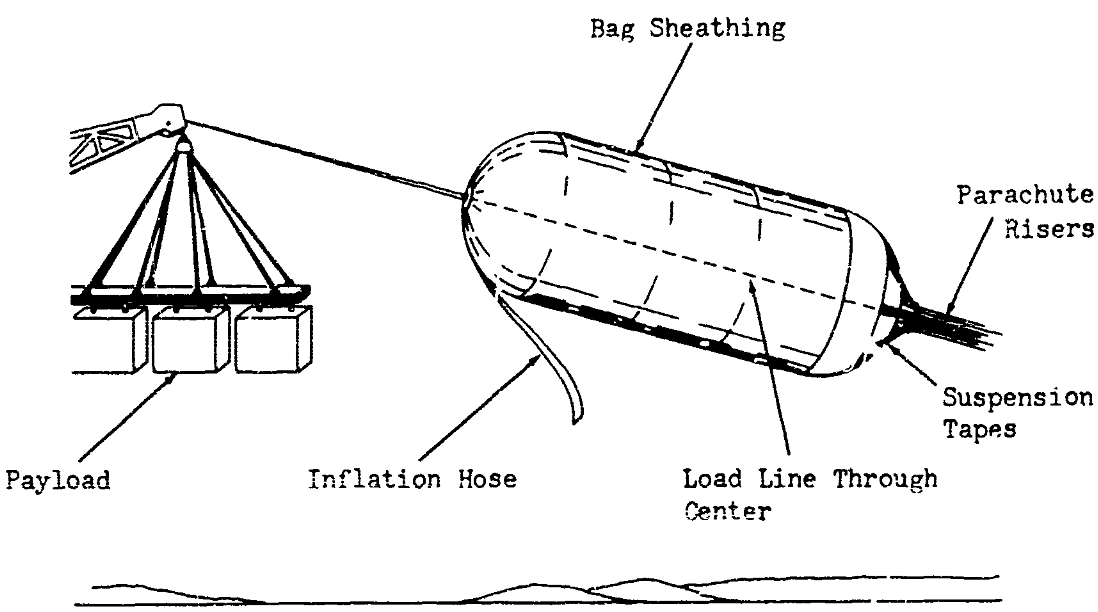


Figure 3-7. Inflation Configuration for Large Air-Filled Ballast Bag Suspended Above the Payload

Several complications become apparent with this type of configuration which may preclude further development in this area. The main problems are the control of the large bubble held in sausage-like fashion when subjected to wind forces during erection, and the excessively long length of the flight train when the ballast bag is suspended between the main balloon and the instrument payload. For example, a 100-foot diameter ballast bag flown at 90,000 feet, has to be inflated to a cylinder about 100 feet long and about

12.5 feet in diameter before it is launched. The flight train will be more than 100 feet longer than normal, making it difficult to keep the main balloon directly over the payload. While the crane is maneuvering about for a dynamic launch, the lower part of the flight train is buffeted by winds which are more likely to differ from those winds on the main balloon 150 to 200 feet higher. Hence, it is felt this system is definitely more wind limited than the static launch. Another problem to be considered is the fabrication techniques required to build a superpressure bag with a line running through it and methods for supporting the bag without setting up excessive stresses on the end caps.

In conclusion, therefore, it is felt that air-filled ballast systems flying less than 70,000 feet or smaller than 50 feet in diameter can be handled and launched dynamically with existing equipment. Larger systems require further study and development in the static erection and launching of single cell poly balloons. At this point, it is believed that static launches are more promising than development of new flight configurations for dynamic launches of large air-filled ballast systems.

C. HELIUM-FILLED SEALED CELL BALLAST SYSTEMS

Ideal Flight Configuration. Since the helium-filled sealed cell ballast system exerts a gross lift, it appears logical to suspend the ballast bag above the main balloon in the flight configuration as shown in Figure 3-8. Depending on the weight and size of the bag and the amount o. helium, however, it may or may not have a net lift when flying at altitude. If the bag should have a positive displacement weight, even when filled with helium at operational altitude, it will have a tendency to flop to one side and rest on top of the main balloon as shown in phantom detail on Figure 3-8. Though it is not known what stresses may be imposed on the ballast bag or the main balloon when this phenomenom occurs, it is not believed to be a grave problem. Heavy loads on top of zero pressure balloons have been successfully flown before without unusual stress occuring on the balloon fabric. As for the ballast bag, if part of its weight rests on the main balloon, then it is logical to assume that the stresses exerted by the load tapes on the bag are not any higher than if the bag were suspended below the flight train. Since the bag does contain helium, however, if the bag does have a positive displacement weight, it will be less than the weight of the empty bag and most certainly less than an air-filled bag.

Before proceeding on this point, consider the operation of the sealed cell ballast system. If the proper amount of helium is injected into the bag at launch, then, when the system reaches its design daytime altitude, the bag will be superpressured to its design limit. Additionally, at night when sunset effect occurs, the system drops Δh feet to a specific nighttime operating altitude, h_2. If the amount of helium is correct and the system designed properly, the bag will be fully deployed

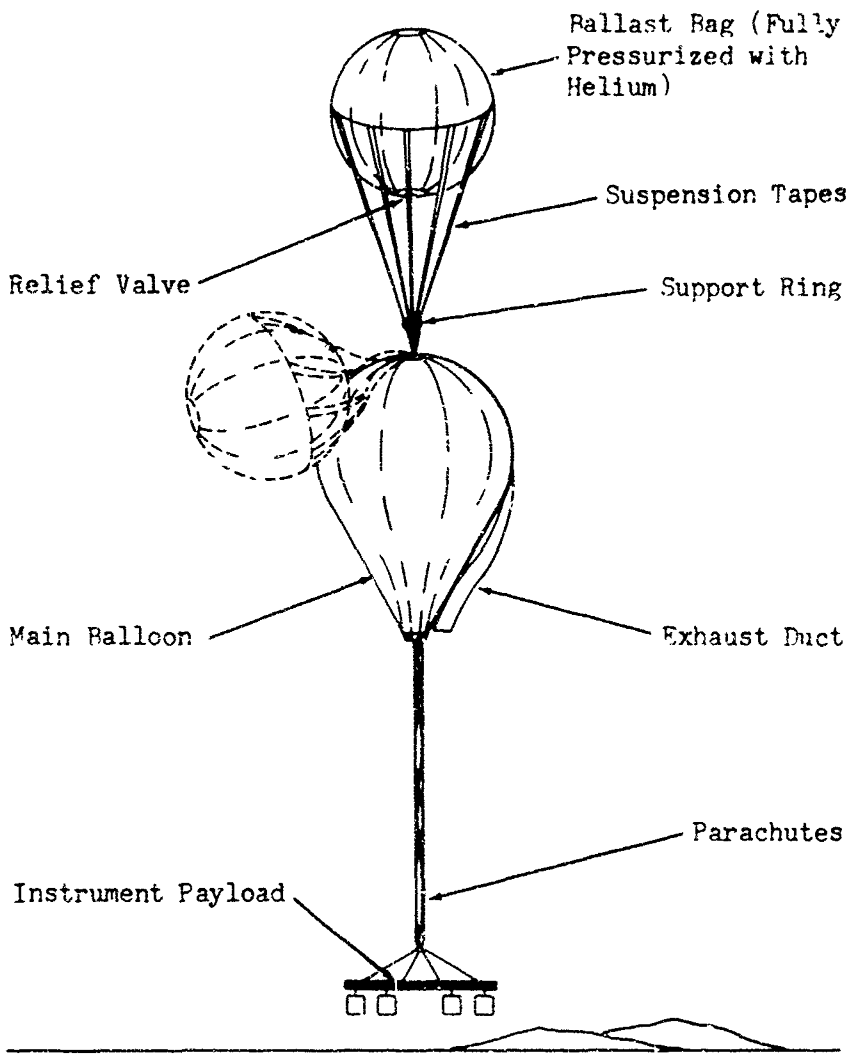


Figure 3-8. Helium-Filled Sealed Cell Ballast System Flight Configuration

and have no superpressure at night, providing there is no night superheat. This means that the correct amount of helium to be inserted into the bag can be determined before launch, once the size and nighttime operating altitude of the ballast system are known. Free lift can also be determined at launch. The gross lift of the ballast bag at night, assuming zero superpressure and superheat, is given by the following formula:

$$G_{b_2} = 4/3 \pi r^3 \, g_{L_2},$$

where

g_{L_2} is the specific lift of helium at night operating altitude (lb./cu.ft.).

The weight of the bag, neglecting weight attributed to fittings and suspension tapes, is given by:

$$W = 4\pi r^2 w_b \quad ,$$

where

w_b is the unit weight of the bag fabric (lb./sq.ft.).

The free lift of the bag at night (F_{b_2}) is:

$$F_{b_2} = G_{b_2} - W.$$

If the ballast bag's free lift percentage of its gross weight is equal to or greater than the main balloon's free lift percentage then the balloon system in the configuration shown in Figure 3-8 should experience no new problems when erected, launched or while ascending. For example, during erection when both the main balloon and the ballast bag are allowed to fly up to the launch position, if the ballast bag's percentage of free lift is equal or greater than the main balloon's percentage, then the bag should never lag behind the main balloon.

Since it is common practice to launch zero pressure balloons with 10 percent free lift, we shall stipulate that the ballast bag have 10 percent or more free lift when on the ground. Notice at this point that for a given operating altitude and bag weight, the net lift of the bag is proportional to bag radius. Therefore, from the above forumlas,

$$\frac{r g_{L_2}}{w_b} \geq 3.3$$

The minimum bag radius (r_{min}) that satisfies this equation, can be determined. From Figure 3-10 in Report No. 1, Δh can be determined for a sealed cell ballast system given a daytime operating altitude, h_1, and bag radius. Given a bag fabric unit weight, w_b, and by employing an iterative process, r_{min} can be determined for daytime operating altitude, h_1. For a given altitude, h_1 and r, the nighttime operating altitude, h_2, and the specific lift of free helium g_{L_2} can be found. Table 3-2 has been made for r_{min}, assuming a 2-mil Mylar ballast bag (w_b = 0.147 lb./sq.ft.) with zero superheat and superpressure at night and a free lift of 10 percent or greater at launch.

TABLE 3-2. MINIMUM SIZE BALLAST BAG RADII FOR HELIUM-FILLED SEALED CELL BALLAST SYSTEMS

Day operating altitude (h_1) (1000 ft.)	Night operating altitude (h_2) x (1000 ft.)	r_{min} (ft.)
60	53.5	5.5
70	62.5	8.9
80	71.0	13.5
90	82.7	23.5

All systems with ballast bags having a radius larger than r_{min} can be filled with the proper metered amount of helium and still have 10 percent free lift when launched and when at altitude. Ballast bags with a radius smaller than r_{min} have to be filled with an excess amount of helium before launch, and the excess helium valved out while the system ascends to operating altitude. This condition, of course, imposes an additional operational requirement to the ballast system while ascending to altitude. As the system ascends, if the bag is equipped with a self-regulating valve, the system automatically releases the excess helium when the superpressure in the bag exceeds the allowable design pressure. The valve will have to be designed to allow the maximum flow rate of gas out of the bag to match the rate of change in differential pressure on the bag while ascending. In addition, the valve will have to be remotely controlled so that not too much helium is valved out when the bag reaches altitude and the gas inside the bag begins to superheat.

The excess helium inserted into bags smaller than the minimum sizes indicated on Table 3-2 should not be more than that required to give the ballast bag 10 percent free lift. It should be pointed out that 10 percent free lift is obtainable for most bags on the ground, even bags as small as two feet in diameter. The primary problem with small ballast bags that are almost filled with helium is that a relatively high flow rate of excess gas through the relief valve is required when the balloon is initially ascending at a fairly high velocity. This flow rate, in turn, requires larger gas valves in the bag and subsequently more dead weight on the system, thus decreasing the overall system payload capacity.

For a sealed cell ballast system whose free lift is 10 percent or greater at launch, the launching and handling problems are essentially the same as for a double balloon flight train. In this case, however, the top balloon (ballast bag) is a superpressure bag independently fastened to a zero pressure balloon (the main balloon). Once both balloon and bag are inflated and the flight train is erected, the system can be dynamically launched in the usual manner as shown in Figure 3-9.

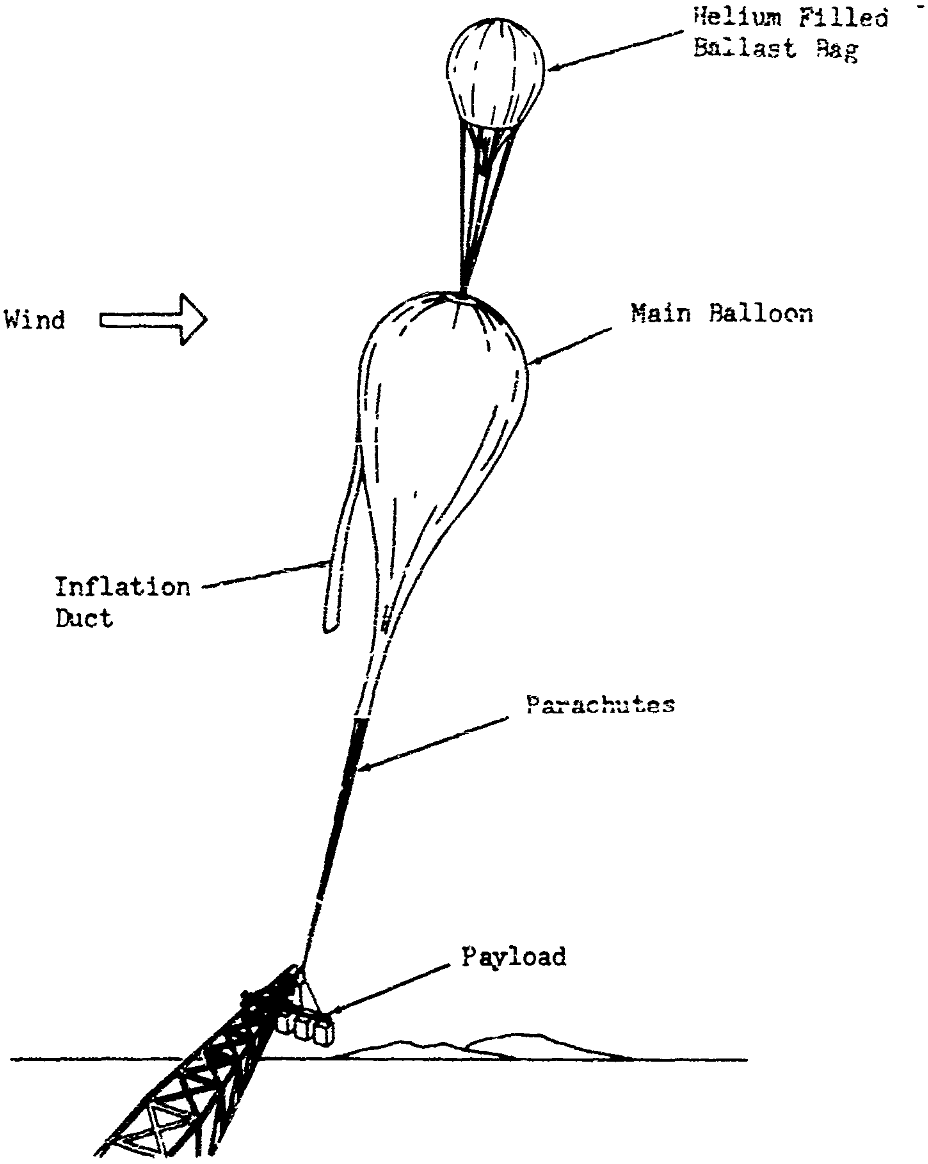


Figure 3-9. Launch Configuration for Ballast Bag Filled with Helium

Now consider the load stresses exerted on the bag fabric when the bag has the greatest amount of free lift. For example, consider a 2-mil, 25-foot radius bag whose daytime operating altitude is 80,000 feet. At night, when the system drops to a lower altitude (75,600 feet), the bag super-pressure decreases and its net lift increases. From Report No. 1 it was found that:

G_{b_2} (Night gross lift) = 192.7 lb.

W (Bag weight) = 115.0 lb.

F_{b_2} = 77.7 lb. (net lift of 25-foot radius bag at 75,600 feet)

Following the example given in Section IIIB with the same 40° load angle, the linear stress, s_{load}, on the bag fabric is now equal to 0.56 lb./ft., or a reduction of less than 0.3 percent of the allowable linear stress due to differential pressure ($s_{\Delta p}$) or of air ballast capability. In addition, when the system rises to its operating altitude during the day, the net lift of the bag decreases, thereby reducing the load stress on the bag fabric to a still smaller figure. Therefore it is concluded that the flight configuration shown in Figure 3-8 has little effect on the ballasting capability on the system.

Inflation Techniques. The primary problem for the flight configuration just described is the method used for inflating both balloons and erecting the flight train. One method for inflating both balloons is shown on Figure 3-10. A regular launch roller arm can be used for holding down the main balloon during its inflation. The inflation of superpressure balloons, however, presents a slightly different problem if the bag material is Mylar. Since pure Mylar film is more slippery than polyethelene or scrim balloon material, it is necessary to use a "Clutch Launcher" that can firmly hold the material in place without the material slipping and minimize the

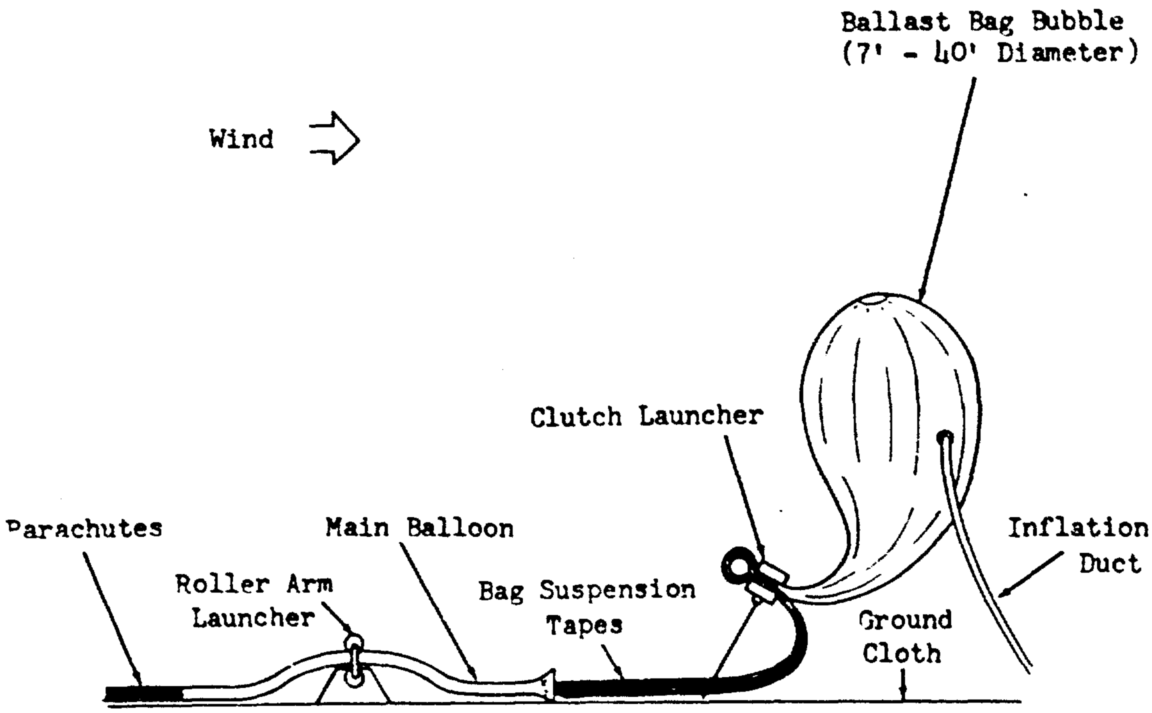


Figure 3-10. Initial Inflation Phase (Ballast Bag Filled with Helium)

stresses on the fabric. The "Clutch Launcher" (Figure 3-11) has been used successfully by the Air Force for numerous superpressure balloon launches and appears to be an ideal launcher for inflating Mylar ballast bags with helium.

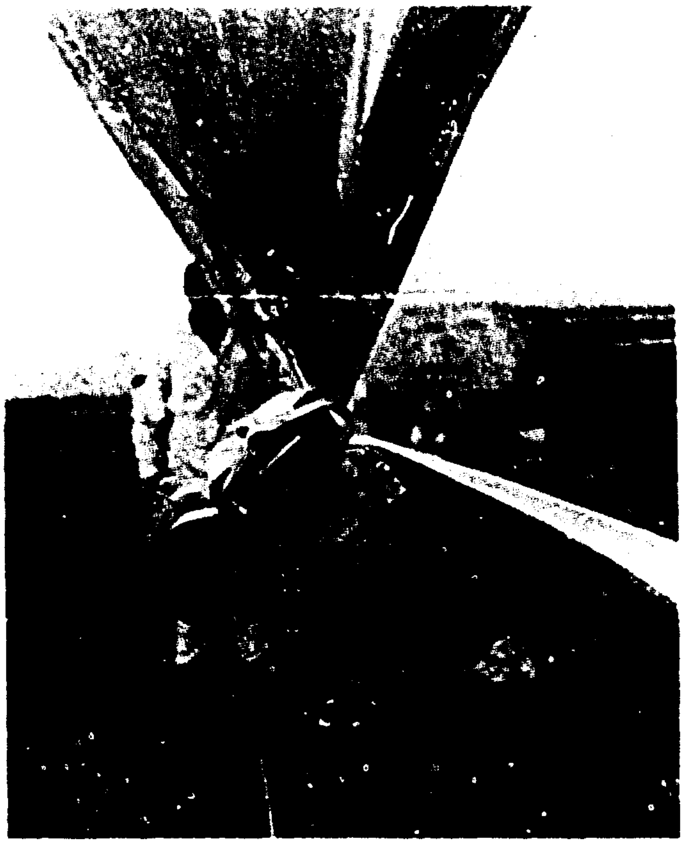


Figure 3-11. AFCRL Clutch Launcher Holding Down a Superpressure Balloon

Basically, the clutch launcher consists of two light, foam-padded clutch blocks which pinch a loop of balloon fabric. The balloon is folded so that all seals occur at the outer edges of the folded system and the clamping blocks are located at these seals. Inside the loop of balloon material is a padded lightweight roller which prevents the loop of balloon fabric from slipping through the clutch blocks. When the superpressure balloon is filled with the right amount of helium, the clutch blocks, which are held down by a ground line, are released allowing the clutch blocks to fly apart and the roller to fly out. A bungee line connected to the roller prevents the roller from flying out too far and striking personnel around the balloon and also allows the roller to swing clear of the balloon as it rises.

The exact sequence and timing for inflating both balloons depends greatly on the size of the ballast bag and the required amount of helium in the bag at launch. For ballast systems operating at high altitudes, a smaller bubble of helium is required on the ground before launch than for systems operating at lower altitudes. Even though it was stipulated that the bag have at least 10 percent or more free lift, ballast bags with small net lift will barely be able to lift the end of the main balloon. Also for these ballast bags with relatively small bubbles of helium (small ballast systems or those operating at high altitudes), there is the additional problem of the bag behaving like a tethered balloon buffeted about by winds while suspended from the main balloon during the inflation and flight train erection. The buffeting of the ballast bag bubble exerts high shearing stress on the main balloon until the system is launched.

Therefore, it is preferable that the inflation of the ballast bag and main balloon be completed at the same time. A sheath can be wrapped around the suspension tapes and excess fabric of the ballast bag to prevent it from sailing with the wind while the balloons are inflated and erected. The sheath can be ripped off at launch by a rip cord, allowing the bag to fully deploy while ascending to altitude.

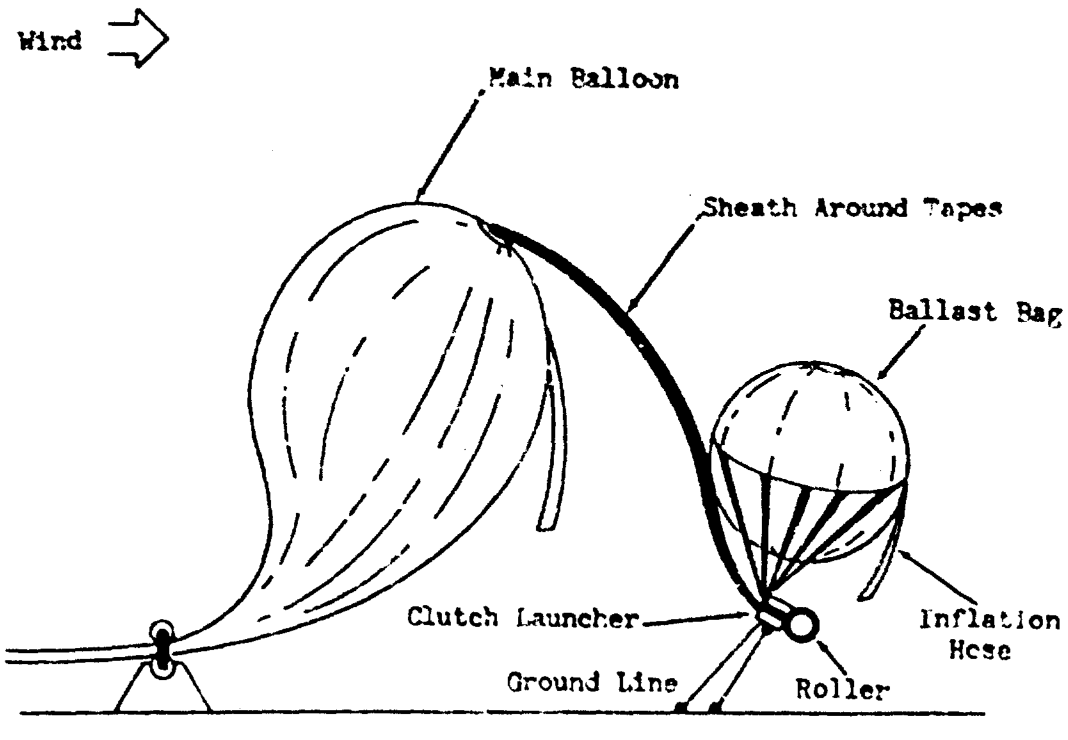


Figure 3-12. Configuration of Ballast Bag Filled with Helium Before Erection of Flight Train

While the ballast bag and the main balloon are inflated at the same time, the ballast bag should be held as close as possible to the main balloon while the top fitting of the balloon begins to rise. If the suspension tapes and excess bag fabric are long enough, the inflation can be accomplished as depicted in Figure 3-12. Otherwise the ballast bag should first be fully inflated and slowly be picked up by a boom crane and swung into position while the main balloon is inflated and begins to erect as shown in Figure 3-13. The primary difference between the inflation phase configurations shown in Figures 3-12 and 3-13, is that the length of the suspension tapes and excess bag fabric is not long enough to permit the main balloon to be fully inflated and its top fitting erected while the clutch launcher for the ballast bag is held down to the ground. The inflation procedure shown in Figure 3-13 is definitely more complex and hazardous to personnel and the main balloon especially when the clutch launcher is released.

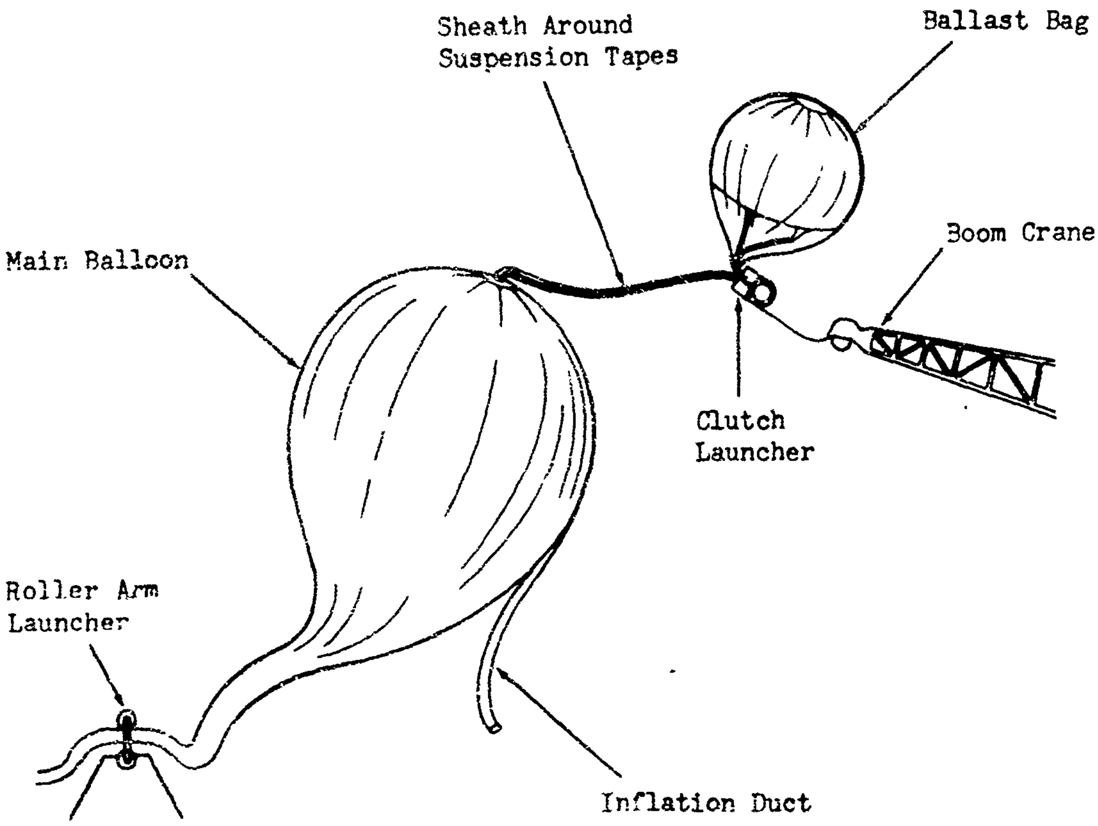


Figure 3-13. Inflation Configuration of Ballast Bag Filled with Helium with Short Suspension Tapes

Before considering this second inflation method a check should be made to determine the extra dead weight required for lengthening the suspension tapes or adding an extra cable length between the top fitting

of the main balloon and the support ring where the bag suspension tapes are tied together. If this extra weight does not diminish the system payload capacity below the minimum requirements, it is preferable that the clutch launcher be anchored to the ground and the support tapes and cables between the two balloons be lengthened.

Handling and Launch Techniques. Once the main balloon and ballast bag are inflated with the correct amount of helium the erection phase may begin. The clutch launcher is first released allowing the ballast bag to swing up over the top of the main balloon. When the bag is almost over the main balloon, the roller arm launcher can release the main balloon. Both the ballast bag and main balloon can rise together, thus erecting the flight system to the launch configuration as shown in Figure 3-9.

If the ballast bag has a very high net lift and can actually lift the top of the main balloon, it may be possible to fill the ballast bag first while filling the main balloon and release the ballast bag from the clutch launcher before the main balloon has a large enough bubble to lift its own top fitting. (Figure 3-14). In this manner the ballast

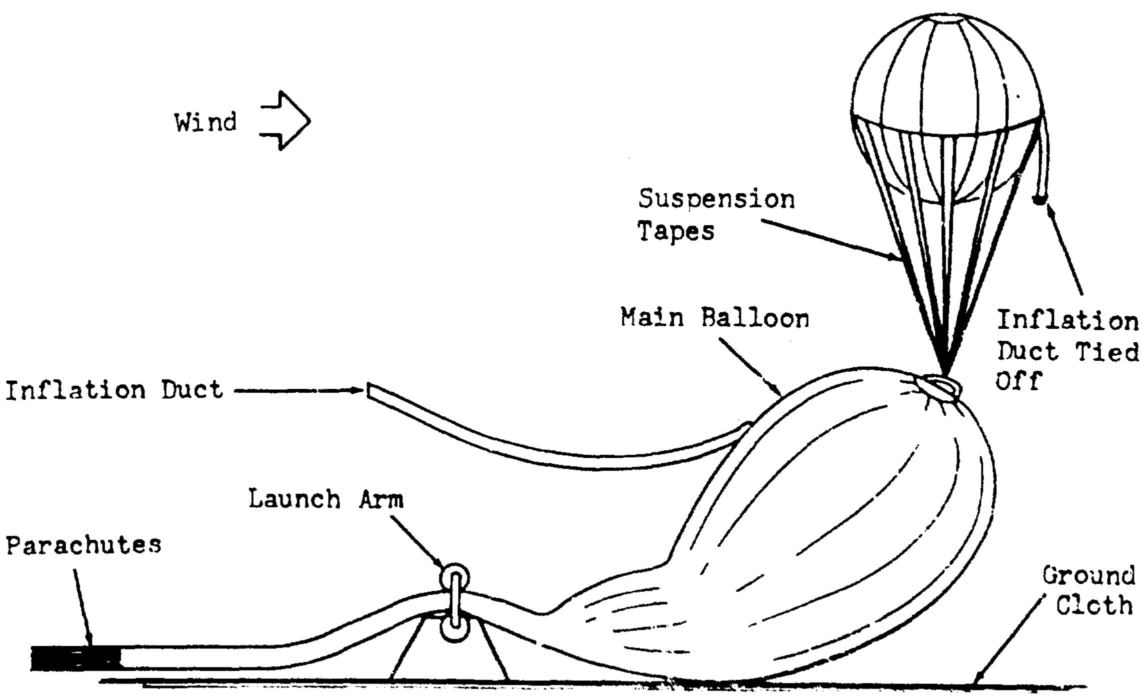


Figure 3-14. Inflation Configuration of High Lift Ballast Bag

bag is allowed to hold the main balloon bubble up while the inflation is completed on the main balloon. When the main balloon is fully inflated, the roller arm releases the main balloon and the system then erects itself to the launch configuration. Notice, however, that this inflation procedure is definitely wind limited and should be used only when the ballast bag requires enough helium at launch to give it a high net lift and the bubble of helium in the bag is suspended fairly close to the top fitting of the main balloon. In all cases thus far described it is important that the ballast bag have a reasonably tight bubble so that maximum control is possible until the system is erected and launched.

Other Flight Configurations. Let us now consider other possible flight configurations for sealed cell systems where the ballast bag has less than 10 percent lift or even a positive weight. Though theoretically there are no launching restrictions in relating to the size of the helium filled bag on top of the main balloon, it may not be desirable to insert excess helium into the ballast bag and valve it out while the system ascends. If the helium-filled bag were located elsewhere in the balloon system,then the primary problems are control of the helium bubble and the orientation (up and down) of the ballast bag, especially when it has lift at night operating altitude and weight when fully pressurized at day operating altitude. One possible flight configuration is shown in Figure 3-15 where the bag has a double set of suspension tapes;

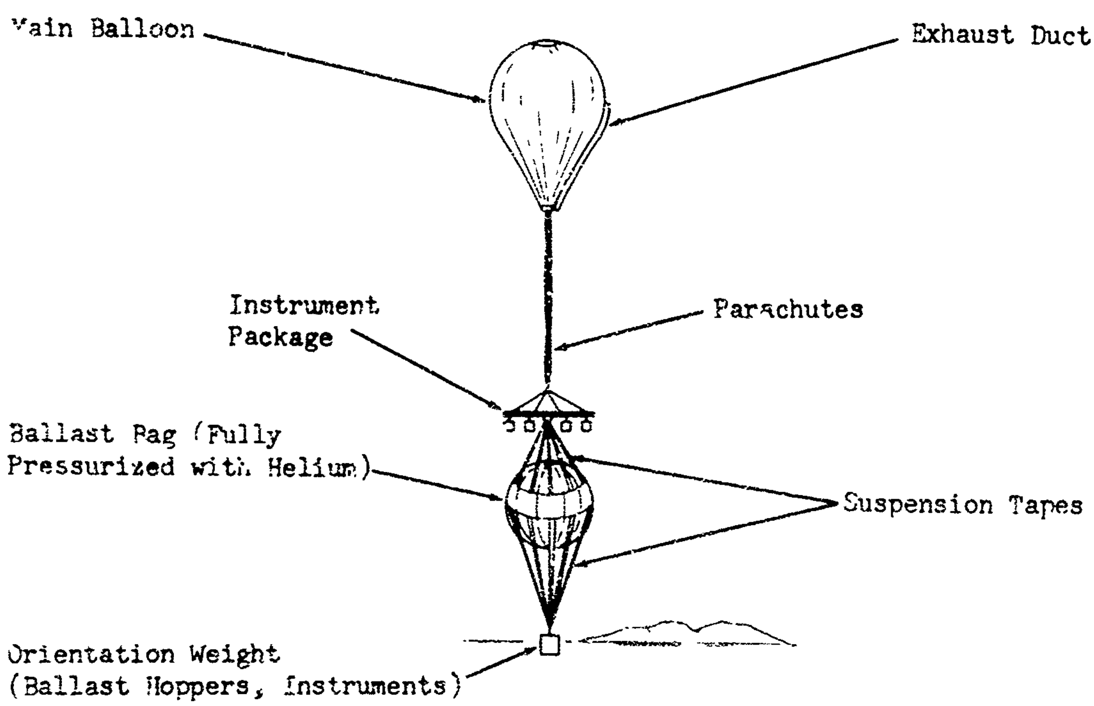


Figure 3-15. Helium-Filled Sealed Cell Ballast System Slung Under Payload

one set of tapes suspends an "orientation" weight onto the bag itself so that the bag is always held down even when it has free lift; and the other set of tapes suspends the bag and the orientation weight underneath the payload bar.

The orientation weight, which can range from 5 to 40 pounds, makes up part of the total payload carried by the balloon system. The orientation weight should be slightly heavier than the maximum lift of the ballast bag if the bag has any positive lift. Otherwise, the orientation weight should be heavy enough to hold the excess fabric of the ballast bag in a downward direction to prevent the bubble of helium in the bag from shifting about and causing the lower end of the bag from floating upward. In either case, it is important that the orientation weight be as light as possible while performing its function so that the linear load stresses on the bag can be kept as low as possible. Depending on the size of the orientation weight required, it can consist of parts of the instrumentation necessary to monitor the condition of the bag (temperature and pressure), and if higher orientation weights are required (20 or more pounds), the compensation ballast hopper can also be supported at this point. The purpose of the compensation ballast is to compensate for lift loss either in the main balloon or ballast system due to helium leaks. Actually, it would be favorable to locate the compensation ballast hopper underneath the ballast bag so that the ballast can fall free of the balloon system. If the ballast hopper were suspended over the ballast bag there is a possibility that the solid ballast would collect on the ballast bag or even damage it.

Basically this type of system is similar to the air-filled sealed cell systems as shown in Figure 3-2 with the exception of the orientation weight slung underneath the ballast bag. An inflation procedure, such as described in Section IIIB for the air-filled system, may be used. The lightweight net can hold the bag in a tight bubble while the bubble is inflated and can prevent the helium lift from floating portions of the bag material around the instrument payload suspended from the boom crane. Care will have to be taken to prevent the double sets of suspension tapes to the ballast bag and the orientation weight from being tangled with the excess bag material when the inflation net is removed. This can be accomplished by taking extra precautions in folding any excess bag material and tapes inside the netting and assuring that the bubble can expand freely while the ballast bag is being filled.

The erection and launching procedure for the flight configuration shown in Figure 3-15, can be the same as that described in Section IIIB for small bubbles (7 to 20 feet in diameter). For large bubbles of helium with low lift, the inflation, erection, and launching problems become more acute for this type of flight configuration.

Another flight configuration possibility for low net-lift helium-filled ballast bags is the suspension of the bag immediately above the instrument payload with a load line running through it as shown in Figure 3-7. As explained for air-filled ballast systems, this configuration presents

unusual and complicated fabrication and launching problems for larger bags.

Another possibility is to join the ballast bag to the main balloon in tandem fashion as is shown in Figure 3-16. Instead of venting the excess helium from the ballast bag to the atmosphere, the helium is allowed to flow through a transfer duct into the main balloon. In this configuration the ballast bag is completely filled and the main balloon remains empty while on the ground. The center fitting between the two balloons contains a relief valve for controlling the transfer of helium and provides a point to which a mainstay cable can be connected for erecting the flight train and allowing the balloon system to be statically launched. Basically this configuration is a tandem balloon system with a superpressure controllable launch balloon on top.

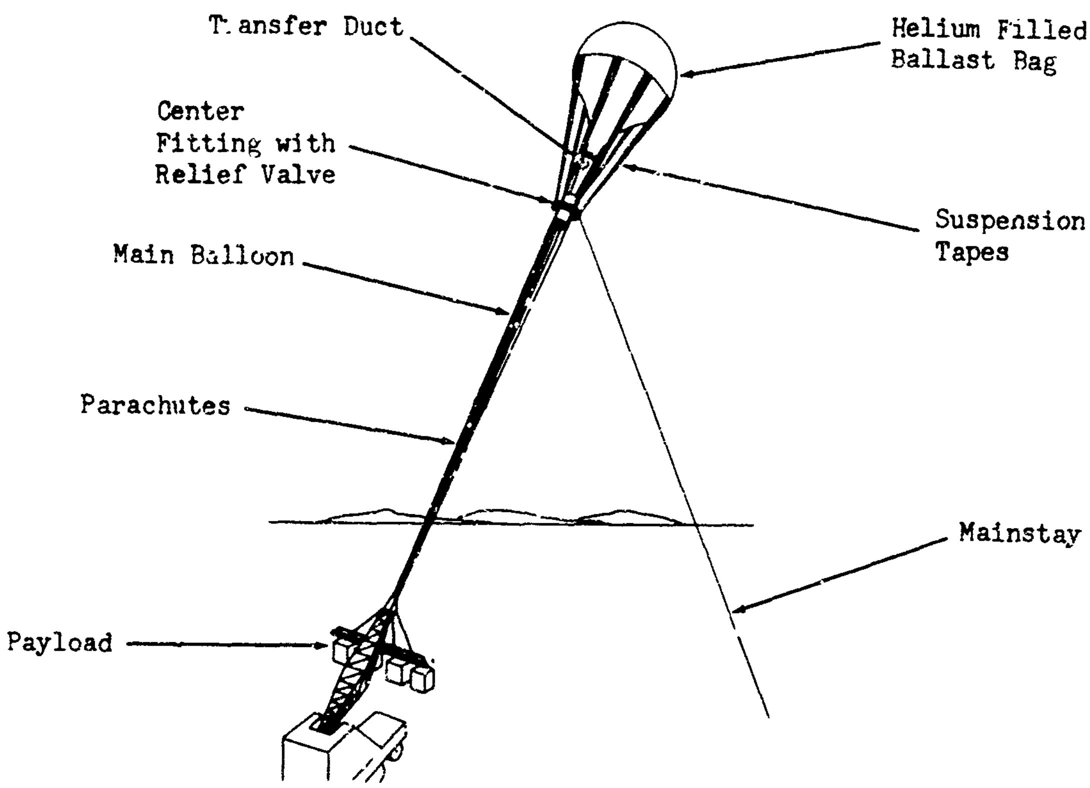


Figure 3-16. Tandem Balloon Configuration for Superpressure Ballast Bag on Top of Zero Pressure Balloon

Ballast bags 16 feet or more in diameter can hold enough helium without becoming superpressured while on the ground to fill the largest main balloon it can ballast as well as to superpressure the ballast bag

itself to the proper operating pressures at operation altitudes of 60,000 feet or more.

Two distinct advantages are apparent for the tandem balloon configuration. The first is that less helium is wasted since the excess helium from the ballast bag is vented into the main balloon instead of into the atmosphere. Second, the tandem balloon configuration lends itself readily to static launch techniques which have been used many times for large tandem balloon systems. Experience has shown in the past that static launches for large tandem balloon systems are less wind sensitive than dynamic launches.

The launching and handling techniques for the tandem balloon configuration of the helium-filled sealed cell systems are similar to those techniques practiced for systems such as Stratoscope II, and Project Voyager. A development program, however, has to be conducted on the design and fabrication of a center fitting with a controllable transfer relief valve and techniques for joining a superpressure balloon to a zero pressure balloon with transfer ducts and a center fitting between them.

D. POWERED BALLAST SYSTEM

Since Report No. 1 concluded that powered systems are not particularly practical using state-of-the-art components, it is difficult at this time to be precise about the flight configurations, launching problems and handling techniques for powered systems. It is not known what type of winches, compressors, or power systems will be eventually developed for these systems; therefore, configurations and techniques that may be used are somewhat speculative. If studies are pursued in this area, it will be necessary to reevaluate the general configuration and techniques described and to determine where changes, if necessary, must be made to make the systems and their associated flight configurations compatible to the newly developed components.

Let us first look at the flight configuration of a mass expulsion ballast system with a compressor as shown in Figure 3-17. The only basic difference between this system and the non-powered mass expulsion ballast system is the additional payload carried on the load bar for the air compressor and the electrical power system. Provided the compressor and power systems are reasonably small in size, the same inflation, erection and launching techniques used for air-filled ballast systems can also be used for air-filled powered ballast systems.

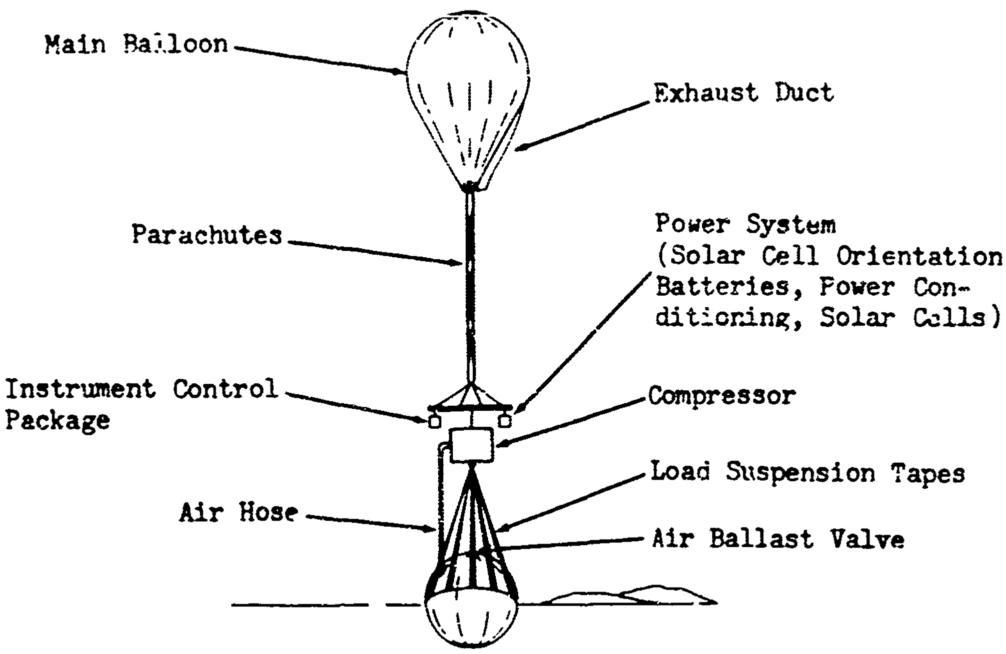


Figure 3-17. Flight Configuration of a Powered Mass Expulsion Ballast System

The winch powered sealed cell ballast system filled with air should be similar to the flight configuration as shown in Figure 3-2 with the exception of a winch on the payload bar and a cable running down to the load suspension tapes of the ballast bag. The cable running from the winch to the ballast bag should be fully reeled in when the system is launched. Again, as for the mass expulsion ballast system with a compressor, the inflation, erection, and launching techniques should also be similar, provided that the winch and power systems are reasonable in size. For large powered air filled ballast systems, the same inherent launching and handling problems exist as for large non-powered air ballast systems.

The helium filled sealed cell ballast system on a powered winch however has a few more complications then the non-powered sealed cell systems filled with helium. In order to keep the power requirements on the winch to a minimum, it was found in Report No. 1 that the net lift of the entire ballast system should be virtually nil when the winch is reeled out and that the only increase in lift should be attributed to the "air" ballast of the system when reeled in. This approach, depending on the net lift of the ballast bag, requires that part of the payload such as the winch and system controls be suspended underneath the ballast bag as shown in Figure 3-18. This configuration imposes a linear stress on the ballast bag approximately proportional to the net lift of the ballast bag itself.

located below the payload. The launching and handling problems for this configuration are similar to those for a non-powered air-filled ballast system.

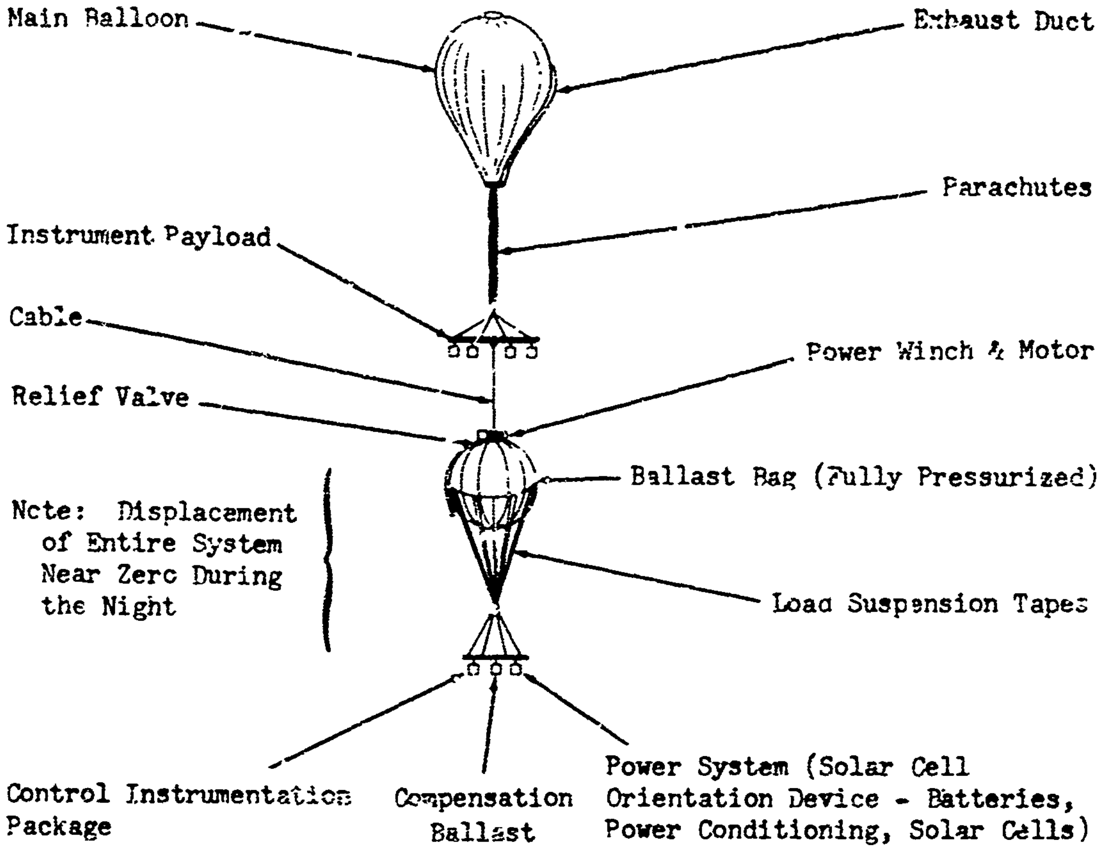


Figure 3-19. Flight Configuration of a Low Net Lift Winch Powered Helium-Filled Ballast System

In conclusion it is believed that powered ballast systems have similar flight configurations and associated launching and handling problems as their counterpart non-powered systems. This conclusion is predicated on the assumption that the power components are not particularly large nor do they require special flight system configurations when applied to the non-powered systems.

Section IV

CONCLUSIONS

In this report some of the more practical aspects in the application of air ballast systems to the control of free flight balloons have been examined. Also examined were instrumentation and controls associated with each type of ballast system. For non-powered air ballast systems (mass expulsion and sealed cell types) it appears that off-the-shelf transducers for pressure and temperature can meet the requirements for all sizes of ballast systems. The standard A/D conversion units, VCO's and other similar analog conversion techniques can also be obtained, either through design or use of off-the-shelf components, for telemetering the required data to ground control stations using standard balloon telemetry equipment. Although higher accuracies and resolutions are required for large ballast systems, especially for differential pressure and altitude measurements, the overall costs for instrumentation are approximately the same for all sizes of ballast systems.

The required ballast control valves for air ballast systems, however, are not readily obtainable and those that are available generally require some modification for adaptations to the specific requirements of a particular ballast system. For example, simple mechanical spring type relief valves for small (25 foot diameter or smaller) ballast bags are suitable if modified to allow remote electrical actuation for more accurate control of the internal pressure of the bag. Mechanical spring type relief valves are available with setting accuracies about ±10 percent. Large ballast bags, however, require more accurate pressure settings at very low differential pressures and this accuracy cannot be maintained by simple spring-action relief valves. Specially designed EV-13 type helium valves will have to be designed along with appropriate circuitry and low pressure differential transducers for automatically controlling pressures within a large sealed cell ballast bag.

Instrumentation and controls for powered air ballast systems at this time cannot be discussed in detail because the major components, such as light-weight, low powered winches and compressors, are not available. When development work in this area specifically aimed at the requirements for powered air ballast systems is accomplished, instrumentation and controls for powered systems should be available utilizing off-the-shelf components.

The flight configuration of an air ballast system is dependent on both the gas used inside the ballast bag and the size of the bag. The launching and handling problems associated with the flight configuration of an air ballast system depends not only on the size of the bag but also on the operating altitude of the system. The higher the altitude at which the system operates the greater the gas expansion. Consequently, for a

given size bag, a smaller amount of gas is required at ground level for high altitude flights.

In determining the flight configuration of an air ballast system, it is necessary to consider the handling and launching problems associated with the system. For air-filled ballast bag systems it was found that ballast bags 50 feet in diameter or larger were too difficult to handle or launch with conventional equipment and techniques. It is concluded therefore that new launch equipment and techniques, along with new handling techniques, must be developed in order to launch and fly large air-filled ballast systems.

Helium-filled ballast systems, however, lend themselves generally to conventional handling and launch techniques, especially for large ballast bags. Still, there are some problems associated with helium-filled ballast bags that have less than 10 percent net lift at launch. If the bag is over-filled with helium to achieve more than 10 percent free lift at launch, the excess gas must be vented off as the system ascends to operational altitude. While this is not considered a critical problem, it is necessary to ensure that the relief valve is properly designed to vent out the excess helium at the proper rate. There are flight configurations for helium-filled ballast bags with less than 10 percent free lift which can be handled with conventional equipment and techniques. However, for some of these configurations, new balloon fabrication techniques must be developed before these flight configurations can be used.

In conclusion, air ballast systems can be instrumented and flown in most cases with conventional or off-the-shelf components and equipment. Systems using large payloads are more difficult to handle and launch than small payload systems. There do not appear, however, to be any design limitations in the size of the ballast system as far as handling, launching, or instrumentation other than limitations imposed by the fabric parameters or the ballast bag, as discussed in detail in Report No. 1. In addition, balloon flight systems with helium-filled ballast bags can not only carry much greater payloads than air-filled bag systems, but, especially for large ballast systems, are also easier to handle and launch.

APPENDIX A

DETERMINATION OF EXHAUSTING TIME FOR PRESSURIZED SPHERES WITH CIRCULAR ORIFICES

A spherical balloon is filled with air or helium under pressure P_1. When the ballast valve with a circular orifice of area A_c is opened, the differential pressure, ΔP, drops as the gas inside the bag is exhausted through the valve. The problem is to determine the time it takes, once the valve is opened, for ΔP to drop to zero. Using Figure A-1, the following assumptions are made:

1. Stretch of the bag is negligible.

2. No heat transfer occurs during exhaust stage; that is, we have adiabatic expansion of gases:

$$\text{Adiabatic expansion:} \quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \tag{A-1}$$

3. Flow of the gas through the valve is described by compressible adiabatic flow (w) through a circular orifice:

$$w = CA_c\, P_2 \sqrt{\frac{2g_c}{RT_1} \left(\frac{k}{k-1}\right)\left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}} \left[\left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}} - 1\right]} \tag{A-2}$$

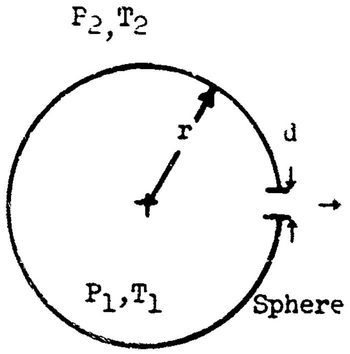
where,

C = orifice coefficient (0.61)

R = gas constant (air = 53.5, helium = 1.66)

g_c = gravity constant (32.2 ft./sec.^{2})

w = flow rate (lb./sec.)



A_c = circular orifice area

P_1, T_1 = pressure and temperature inside sphere

P_2, T_2 = atmospheric pressure and temperature

d = diameter of orifice

V_b = sphere (bag) volume

Figure A-1. Pressurized Sphere with Circular Orifice.

Substituting for T_1 from equation (A-1) we get:

$$w = \beta A_c \sqrt{\left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}} - 1}\ , \tag{A-3}$$

where $$\beta = CP_2 \sqrt{\frac{2\ g_c\ k}{R\ T_2\ (k-1)}}\ . \tag{A-4}$$

Over a small increment of time Δt, the amount of gas leaving the sphere is equal to the change in density of the gas inside the sphere times its volume, or:

$$w\ \Delta t = -V_b\, \Delta \rho \tag{A-5}$$

From the perfect gas law and equation (A-1):

$$\rho_1 = \frac{P_1}{RT_1} = \frac{(P_2)^{\frac{k-1}{k}}}{RT_2} \cdot P_1^{1/k} \tag{A-6}$$

If we assume Δt to be small, then $\frac{\Delta P}{P}$ will be small over this period of time. Hence the change in density of gas $(\Delta \rho)$ can be determined from equation (A-6) in the following manner:

$$\Delta\rho = \frac{1}{RT_2} \cdot P_2^{\frac{k-1}{k}} \left[P_1^{1/k} - (P_1 - \Delta P)^{1/k} \right]$$

$$= \frac{1}{RT_2} \cdot P_2^{\frac{k-1}{k}} \cdot P_1^{1/k} \cdot \left[1 - \left(1 - \frac{\Delta P}{P_1}\right)^{1/k} \right]$$

$$\approx \frac{1}{RT_2} \cdot P_2^{\frac{k-1}{k}} \cdot P_1^{1/k} \cdot \left[1 - 1 + 1/k \frac{\Delta P}{P_1} \right] \tag{A-7}$$

$$\text{thus, } \Delta\rho \approx \frac{1}{Rk\ T_2} \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} \cdot \Delta P \tag{A-8}$$

Substituting equations (A-3) and (A-8) into equation (A-5) produces the following differential equation:

$$\Delta t = - \frac{V_b \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} \Delta P}{Rk\ T_2\ \beta\ A_c \sqrt{\left(\frac{P_1}{P_2} \right)^{\frac{k-1}{k}} - 1}} \tag{A-9}$$

If we integrate both sides of equation (A-9) from time $t = 0$ to $t = t_c$ (exhaust complete), we can determine the total exhaust time t_c by the following equation:

$$t_c = \frac{-V_b}{P_2 A_c C \sqrt{\frac{2 g_c k^3 RT_2}{k-1}}} \int_{P_1}^{P_2} \frac{dP}{\left(\frac{P}{P_2} \right)^{\frac{k-1}{k}} \sqrt{\left(\frac{P}{P_2} \right)^{\frac{k-1}{k}} - 1}} \tag{A-10}$$

The integral in equation (A-10) may be integrated directly by the following substitution:

$$\left[\frac{P}{P_2} \right]^{\frac{k-1}{k}} = \sec^2 \xi \ . \qquad \text{(A-11)}$$

Then by differentiating both sides of equation (A-11):

$$dP = \frac{2k\ P_2}{k-1} \left[\sec \xi\right]^{\frac{2k}{k-1}} \tan \xi \ d\xi \qquad \text{(A-12)}$$

Substitution of equations (A-11) and (A-12) into (A-10) yields

$$t_c = - \frac{V_b}{A_c\ C \sqrt{\frac{g_c\ k\ (k-1)\ RT_2}{2}}} \int_{\xi_1}^{\xi_2} (\sec \xi)^{2/(k-1)}\ d\xi \qquad \text{(A-13)}$$

where $\xi_{1,2} = \text{arcsec} \left(\frac{P_{1,2}}{P_2} \right)^{\frac{k-1}{2k}}$

If the bag is filled with air, $k = {}^{C_P}/_{C_V} = 1.4$; thus

$$t_c = - \frac{V_b}{A_c\ C \sqrt{.28 g_c\ RT_2}} \cdot \int_{\xi_1}^{\xi_2} \frac{1}{\cos^5 \xi}\ d\xi \ . \qquad \text{(A-14)}$$

Let $\gamma_{air} = \dfrac{V_b}{C \sqrt{.28\ g_c\ RT_2}}$; thus (A-15)

$$t_c = - \frac{\gamma_{air}}{A_c} \left[\frac{\sin\xi}{4\cos^4\xi} + \frac{3}{8}\left(\frac{\sin\xi}{\cos^2\xi} + \ln(\sec\xi + \tan\xi) \right) \right] \Bigg|_{\xi_1}^{\xi_2}$$

Let $x = \cos^2\xi = \left(\frac{P}{P_2}\right)^{\frac{1-k}{k}}$ (from Equation (A-11));

then as a final result for an air filled bag:

$$t_c = - \frac{\gamma_{air}}{A_c} \left[\frac{\sqrt{1-x}}{4x^2} + \frac{3}{8}\frac{\sqrt{1-x}}{x} + \frac{3}{8}\ln\left(\frac{1+\sqrt{1-x}}{\sqrt{x}} \right) \right] \Bigg|_{x_1}^{x_2} \tag{A-16}$$

where $x_{1,2} = \left(\frac{P_2}{P_{1,2}} \right)^{.286}$.

Similarly, for a helium filled bag, where $k_{He} = 1.66$

$$t_c = - \frac{\gamma_{He}}{A_c} \left(\frac{\sqrt{1-x}}{2x} + \frac{1}{2}\ln\left[\frac{1+\sqrt{1-x}}{\sqrt{x}} \right] \right) \Bigg|_{x_1}^{x_2} \tag{A-17}$$

where $x_{1,2} = \left(\frac{P_2}{P_{1,2}} \right)^{.398}$, $\gamma_{He} = \frac{V_b}{C\sqrt{.55\, g_c\, RT_2}}$.

For a specific example, assume a 100 foot diameter 2 Mil Mylar ballast bag at 80,000 feet altitude pressurized with air to S_1 = 10,000 psi. The problem is to determine what orifice area (A_c) is required to exhaust the bag within 30 minutes. The initial internal pressure P_1 of the ballast bag is determined by

$P_1 = P_2 + \Delta P$, where

$$\Delta P = \frac{24\, S_1\, t_b}{r(1 + 3S_1/E)} \tag{A-18}$$

Summary of conditions at 80,000 feet altitude:

$P_2 = 58\#/ft^2$		$r = 50$ feet
$T_2 = 398°R$		$t_c = 30$ minutes (1800 seconds)
$R_{air} = 53.5$ °/ft		$S_1 = 10,000$ psi
$k_{air} = 1.4$		$t = .002''$
$C = 0.61$		$E = 800,000$ psi
$g_c = 32.2$ ft./sec^2		

From equation (A-18),

$$P_1 = 58.0 + 9.27 = 67.25\ \#/ft^2$$

From equation (A-15)

$$\gamma_{air} = \frac{\frac{4}{3}\ \pi\ 50^3}{.61\ \sqrt{.28 \cdot 32.2 \cdot 53.5 \cdot 398}} = 1.945 \times 10^3$$

From equation (A-16) then;

$$1800 = \frac{1.945 \text{x} 10^3}{A_c} \left[\frac{\sqrt{1-x}}{4x^2} + \frac{3}{8} \frac{\sqrt{1-x}}{x} + \frac{3}{8} \ln\left(\frac{1+\sqrt{1-x}}{\sqrt{x}}\right)\right]\Bigg|_{1.0}^{.9584}$$

or

$$A_c = .228\ ft^2$$

$$A_c = \frac{\pi d^2}{4} = .228\ ft^2$$

or,

$$d = 0.54\ ft = 6.50\ inches$$

Thus we find that a 100 foot bag should have a $6\frac{1}{2}$ inch diameter valve in order that all of its air pressure be valved out within 30 minutes. If we

only require [illegible] percent of the pressure to be valved out in 30 minutes, then from equation (A-15), we find that a valve 5.3 inches in diameter will be sufficient. At 80,000 feet altitude, a 100 foot diameter bag can contain 105 pounds of air ballast. Thus if we use a 5.3 inch valve, approximately 6.6 pounds of air ballast will be left after 30 minutes. It is therefore concluded that a 6 inch valve should be sufficient for exhausting a 100 foot diameter air pressurized bag at 80,000 feet within the time of sunset effect.

If the bag were filled with helium, equation (A-17) is then used:

$$R_{He} = 386°/ft$$

$$C = 0.61 \text{ (assumed)}$$

$$k = 1.66 ,$$

thus $\gamma_{He} = 5.19 \times 10^2$.

Using equation (A-17):

$$1800 = \frac{5.19 \times 10^2}{A_c} \left[\frac{\sqrt{1-x}}{2x} + \frac{1}{2} \ln \left(\frac{1+\sqrt{1-x}}{\sqrt{x}} \right) \right]_{1}^{.943}$$

$$A_c = .0710 \text{ ft}^2 , \quad d = 3.61''$$

Thus, if the 100 foot diameter bag were pressurized with helium instead of air, a 3.61 inch diameter valve could fully exhaust the bag within the required 30 minutes.

APPENDIX B

DETERMINATION OF EXHAUST REQUIREMENTS FOR AN ASCENDING SEALED CELL SYSTEM

Assume a bag containing a certain quantity of gas ascends to some altitude h_o at which point the bag has a differential pressure ΔP_o. The relief valve is assumed to fully open when the differential pressure reaches ΔP_o and remains open until the balloon reaches altitude. In actual practice, the valve should shut whenever the differential pressure drops below the desired final differential pressure ΔP_f. For simplification, however, we make the former assumption in order to assure ourselves that the valve has sufficient capacity to valve off enough excess gas without exceeding the maximum allowable differential pressure in the ballast bag. If the valve is large enough, the valve will shut periodically allowing the pressure to build back up in the bag while ascending, and open whenever the differential pressure exceeds ΔP_o.

From equations (A-2) and (A-5) in Appendix A;

$$\frac{dP_1 / (P_1/P_2)^{\frac{k-1}{k}}}{P_2 \sqrt{[P_1/P_2]^{\frac{k-1}{k}} - 1}} = - \left[\frac{CA_c}{V_t} \sqrt{\frac{2g_c \; k \; R_b T_2}{k-1}} \right] dt \qquad \text{(B-1)}$$

At this point, a basic assumption is made that the atmosphere over the region of interest is isothermal and that the ratio between the pressure in the ballast bag and outside ambient pressure remains constant while the valve is open and the bag is ascending i.e.,

$$P_1 = \alpha_o P_2 , \qquad \text{(B-2)}$$

where $P2_{t=0} \; (\alpha_0 - 1) = \Delta P_o$ (initial opening differential pressure) and α_o = constant.

Equation (B-1) therefore can be rewritten as:

$$\frac{dP_1}{P_1} = - \lambda \, dt, \text{ where} \qquad \text{(B-3)}$$

$$\lambda = \text{constant} = \left[\frac{CA_c}{V_b} \sqrt{\frac{2g_c \quad k\, R_b T_2}{k-1}} \right] \left[\frac{\sqrt{\alpha_o^{\frac{k-1}{k}} - 1}}{\alpha_o^{1/k}} \right]$$

The differential equation (B-3) is solved by integrating both sides of the equation

$$P_1 = \alpha_o \, P_{2_{t=0}} \cdot e^{-\lambda t} \qquad \text{(B-4)}$$

Note at time $t = 0$, $P_1 = \alpha_o \cdot P_{2_{t=0}}$, where $P_{2_{t=0}}$ is the ambient pressure when the valve first opens.

For further simplification, it is assumed that the ambient pressure follows the basic hydrostatic law:

$$P_2 = P_{2_{t=0}} \cdot e^{-\{g^*/[g_c RT]\}z} \qquad \text{(B-5)}$$

From equation (B-4), λ = constant; assume $g^* = g_c$ (constant gravity). Then from equation (B-5)

$$v = dz/dt = \lambda R_a T_2 = \text{constant} . \qquad \text{(B-6)}$$

That is to say, if it is assumed that α_o = constant, then the ascent velocity v must also be a constant. It is therefore found that given an initial opening pressure ΔP_o and an ascent velocity v, the required orifice size of the relief can be determined:

$$A_c = \frac{V_b \, v \, \alpha_o^{1/k}}{R_a C \sqrt{\frac{2kg_c \, R_b T_2^{\,3}}{(k-1)} \left[\alpha_o^{\frac{k-1}{k}} - 1 \right]}} , \qquad \text{(B-7)}$$

where

$$\alpha_o = 1 + \frac{\Delta P_o}{P_{2_{t=0}}}$$

Note that R_a is the gas constant for ambient air and R_b is the gas constant for the gas inside the bag. If the bag is filled with air, $R_b = R_a$.

As an example, consider a 16 foot diameter 2 mil Mylar bag filled with helium which is launched with 20 percent free lift. The first step in the problem is to determine at what altitude the bag becomes fully pressurized. It is assumed that the bag can withstand a skin stress up to 12,000 psi and that the relief valve is designed to fully open at that setting.

From equation (A-18) in Appendix A, this skin stress is equivalent to a bag differential pressure of

$$\Delta P_o = \frac{24 \cdot 12{,}000 \quad .002}{8\ (1 + 3\ 12{,}000/800{,}000)} = 68.6\ \#/ft^2\ .$$

The gross weight of the bag is given as:

$$4 \pi r^2 \quad W_b = 4 \cdot 3.14 \quad 8^2\ (0.0147) = 11.8\#$$

With 20 percent free lift, the gross lift of the gas inside the bag must be:

$$G_{b_2} = (1.20)\ (11.8) = 15.6\#$$

The specific lift of helium on the ground is given as 6.587×10^{-2} lb./ft^3 and the density as 1.06×10^{-2} lb./ft.^{3}. Therefore the mass of helium inside the bag is:

$$\frac{15.6 \text{ lb.}}{6.587 \times 10^{-2}} \times (1.06 \times 10^{-2}) = 2.52 \text{ lb.}$$

From the perfect gas law, $\rho = \frac{P}{RT}$, we can find the mass of helium inside the bag when fully pressurized:

$$2.52 = V_b \quad \rho_1 = \frac{4}{3} \pi r^3 (1+3S_1/E) \quad \frac{P_1}{RT_1} = \frac{\frac{4}{3} \pi r^3 (1+3S_1/E)}{RT_1} \quad (P_2 + \Delta P_o)$$

$$2.52 = \frac{5.8\ (P_2 + 68.6)}{T_2}$$

Altitude h_a which has a corresponding air temperature T_2 and pressure P_2 that will satisfy the conditions of the above equation is now determined. NOTE: Assume $T_2 = T_1$ initially.

By iteration, we find that at h_o = 68,500 feet, the bag becomes fully pressurized and begins venting helium. From analysis of balloon flight trajectories velocities of 1,000 to 1,200 feet per minute are not unlikely at this altitude if the operational altitude of the balloon system is above 68,500 feet.

At 68,500, $P_{2_{t=0}} = 101.4\ \#/\text{ft}^2$. The required area of the relief valve orifice is therefore determined from equation (B-7):

$$\alpha_o = 1 + \frac{68.6}{101.4} = 1.675$$

$$R_a = 53.5\ °/\text{ft.}$$

$$R_b = 386\ °/\text{ft.}$$

$$k = 1.66$$

$$v = 1200\ \text{ft./min.} = 20\ \text{ft./sec.}\ \text{(assume)}$$

$$T_2 = 391\ °R$$

$$A_c = 1.95 \times 10^{-3}\ \text{ft}^2 = .281\ \text{in}^2$$

$$\pi d^2 = A_c = .281\ \text{in}^2$$

$$d = .596\ \text{in.}$$

Therefore a relief valve with an orifice diameter of .596 inch will be able to valve off the excess gas on a 16 foot bag at 68,500 feet ascending at the rate of 1200 feet/minute.

If the operational altitude of the ballast bag is 70,000 feet, the ambient pressure then is:

$$P_2 = 94\ \#/\text{ft}^2$$

Since α_o was determined to be 1.675, then from equation (B-2)

$$\Delta P_f = P_2\ (\alpha_o - 1) = 63.5\ \#/\text{ft}^2\ .$$

This corresponds to a skin stress on the bag of about S_1 = 11,000 psi. Since the operational pressure should be about S_1 = 10,000 psi, then the valve must still remain open for a short time longer in order to bleed the extra pressure in the bag to the right level.

APPENDIX C

DETERMINATION OF LARGEST BUBBLE THAT CAN BE HANDLED BY A 40-FOOT BOOM CRANE

Assume that the ballast bag forms a spherical bubble of a radius r which is suspended a distance x from the top of the boom crane of length L. Assume also that the crane is well padded and that the maximum size bubble rests tangent to the boom and tangent to the level of the base of the boom as shown in figure C-1.

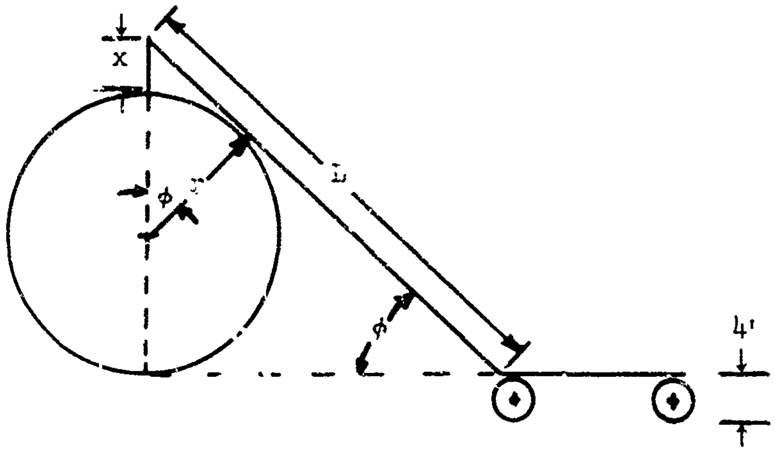


Figure C-1. Determination of Maximum Size Bubble With 40-foot Boom Crane.

If the base of the boom is about 4 feet above the ground then the bubble is kept high enough off the ground that it will not scrape the ground while the crane moves around during a dynamic launch.

From the geometry of the above figure the following equations are written:

$$L \sin \phi = x + 2r \tag{C-1}$$

$$x = r/\cos \phi - r \tag{C-2}$$

Simultaneous solution of equations (C-1) and (C-2) yields the following for r:

$$r = \frac{L \sin\phi}{(\sec\phi + 1)} \qquad \text{(C-3)}$$

To find the maximum value for r for given boom length L, we differentiate r with respect to ϕ and set it equal to zero:

$$\frac{dr}{d\phi} = \frac{L + L\cos\phi - L\tan^2\phi}{(\sec\phi + 1)^2} = 0 \qquad \text{(C-4)}$$

Equation (C-4) reduces to

$$\cos^2\phi + \cos\phi - 1 = 0 \qquad \text{(C-5)}$$

Solving for $\cos\phi$ by the quadratic formula,

$$\cos\phi = \frac{-1 \pm \sqrt{1 + 4}}{2} = 0.615$$

$$\phi = 42°$$

If the boom crane with an extension has a length 40 feet, then from equation (C-3), the maximum bubble radius which can be handled is determined to be:

$$r_{max} = \frac{(40)\ (0.669)}{\frac{1}{0.615} + 1} = 10.2 \text{ feet}$$

From equation (C-1), the distance the bubble is supported below the top of the crane is:

$$x = (40)\ (0.669) - 2\ (10.2) = 6.4 \text{ feet.}$$

The results are summarized in figure C-2.

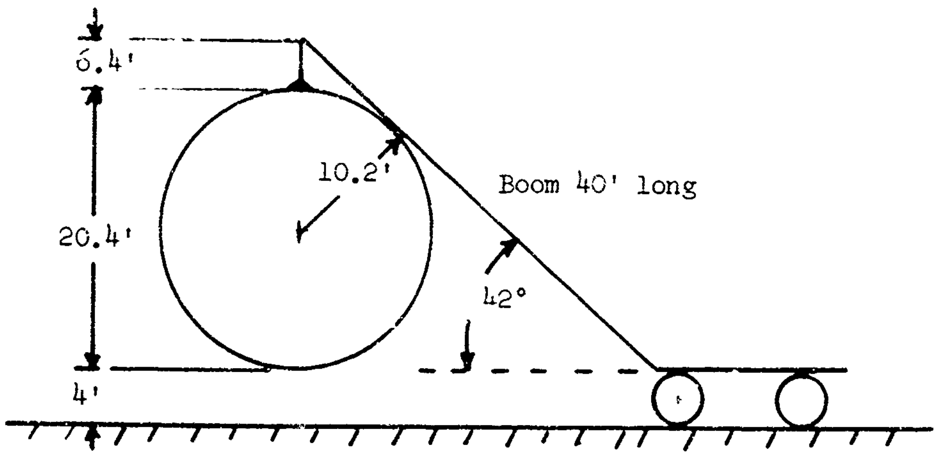


Figure C-2. Maximum Bubble Size With 40-Foot Boom Crane.

GLOSSARY

List of Symbols

Symbol	Definition	Units
A	Air ballast; weight of air in ballast bag less weight of ambient air displaced.	lbs.
A_c	Area of ballast valve orifice	ft^2
E	Modulus of elasticity	$lbs./in.^2$
F	Free lift	lbs.
$F(\Sigma)$	Function of fabric parameter	dimensionless
G_b	Ballast bag gross lift	lbs.
L	Length	ft.
N	Percentage of superheat in main balloon	decimal of ambient air
N_1	Daytime superheat effect: $= \frac{mb}{T_a}$	decimal of T_a
N_2	Nighttime superheat effect: $= \frac{mb}{T_a}$	decimal of T_a
P	Pressure	$lbs./ft^2$
ΔP_o	Differential pressure at time t = 0	$lbs./ft^2$
ΔP_f	Final differential pressure	$lbs./ft^2$
ΔP_b	Pressure in the ballast bag	$lbs./ft^2$
R	Gas constant	ft./°R
R_a	Gas constant for ambient air	53.5 ft./°R
R_b	Gas constant for gas in ballast bag	ft./°R
R_{He}	Gas constant for helium	386 ft./°R
°R	Degrees Rankin	
S	Ballast bag fabric stress	$lbs./in^2$
T	Temperature, general	°R
T_a	Ambient air temperature	°R

Symbol	Definition	Units
T_b	Temperature of gas in ballast bag	°R
T_{mb}	Temperature of gas in main balloon	°R
V_b	Volume of ballast bag, unstretched	ft^3
W_b	Total weight of ballast bag fabric	lbs.
d	Ballast valve orifice diameter	in.
g_c	Gravity constant	32.2 $ft./sec^2$
g^*	Local acceleration of gravity	$ft./sec^2$
g_L	Specific lift of helium	$lbs./ft^3$
h	Altitude	ft.
k	Gas constant $= C_p/C_v$	dimensionless
n	Percentage of superheat in ballast bag	decimal of ambient air temperature
r	Radius of ballast bag	ft.
s	Ballast bag linear fabric stress	lbs./ft.
$s_{\Delta p}$	Ballast bag linear fabric stress due to differential pressure	lbs./ft.
s_{load}	Ballast bag linear fabric stress due to load forces	lbs./ft.
s_{total}	$s_{\Delta p} - s_{load} = s$	lbs./ft.
t	Time	seconds
t_b	Ballast bag fabric thickness	inches
t_c	Time to complete exhausting	seconds
w	Gas flow rate	lbs./sec.
w_b	Ballast bag unit fabric weight	$lbs./ft^2$
w_{mb}	Main balloon unit fabric weight	$lbs./ft^2$
z	Variable altitude	ft.

Symbol	Definition	Units
α_o	Pressure ratio; P_1/P_2	dimensionless
β	Flow rate variable; $CP_2 \sqrt{\frac{2g_c\ k}{RT_2\ (k-1)}}$	$lb./ft^2$-sec
γ	Flow time variable; $\frac{V_b}{C\sqrt{\frac{g_c\ k(k-1)RT_2}{2}}}$	ft^2-sec
Δ	Differential symbol	dimensionless
θ	Load force angle on ballast bag	degrees
θ_b	Superheat in ballast bag	°F; $\theta_b = n T_a$
θ_{mb}	Superheat in main balloon	°F; $\theta_{mb} = NT_a$
ν	Ascent velocity	ft/sec
λ	Time pressure constant	
π	Pi	3.14159
ρ_a	Density of ambient air	$lbs./ft^3$
ρ_b	Density of gas in ballast bag	$lbs./ft^3$
ρ_{He}	Density of helium	$lbs./ft^3$
Σ	Main balloon fabric parameter	dimensionless

Subscripts

1	Conditions during the day; or inside ballast bag
2	Conditions during the night; or outside ballast bag
a	Ambient air
b	Ballast bag

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Vitro Laboratories Silver Spring Laboratory 14000 Georgia Ave.,Silver Spring,Md. 20910	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

FLIGHT CONTROL SYSTEMS AND LAUNCHING TECHNIQUES FOR AIR BALLAST SYSTEMS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific Interim

5. AUTHOR(S) (First name, middle initial, last name)

Allen R. Davidson, Jr.

6. REPORT DATE 6 November 1967	7a. TOTAL NO. OF PAGES 76	7b. NO. OF REFS 2
8a. CONTRACT OR GRANT NO. F19628-67-C-0192 b. PROJECT, TASK, AND WORK UNIT NO. 6665-01-01 c. DOD ELEMENT 65402124 d. DOD SUBELEMENT 632800	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Note 02057-02-2 Scientific Report No. 2 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFCRL-67-0679	

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited. It may be released to the Clearinghouse, Dept. of Commerce, for sale to the general public.

11. SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratories (CRE),L.G.Hanscom Field,Bedford,Massachusetts 01730

13. ABSTRACT

This report examines some of the more practical aspects in the application of air ballast systems to the control of free-flight balloons. Each type of air ballast system, as defined in Scientific Report No. 1, is analyzed for the cost, availability of materials, components, and instrumentation required. In addition, for each type of air ballast system deemed feasible, the possible flight system configurations, associated launching problems, and methods to solve the problems are investigated. It is the conclusion of this report that most air ballast systems can be instrumented and flown with conventional or off-the-shelf components and equipment. Systems using very large payloads are more difficult to handle and launch than smaller payload systems and probably will require some development in new launching techniques and associated equipment.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Air Ballast Balloon Instrumentation Balloon Altitude Control Balloon Launching Techniques						

Unclassified
Security Classification